Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

CSAS

Canadian Science Advisory Secretariat

SCCS

Secrétariat canadien de consultation scientifique

Research Document 2009/022

Document de recherche 2009/022

State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems

État des ressources physiques et biologiques et de certaines ressources halieutiques des écosystèmes des eaux canadiennes du Pacifique

W.R. Crawford[1] and J.R. Irvine[2], editors

Fisheries Oceanography Working Group (FOWG)
Science Branch
Fisheries and Oceans Canada
Pacific Region

[1]Institute of Ocean Sciences, Sidney, BC V8L 4B2

[2]Pacific Biological Station, Nanaimo, BC V9T 6N7

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

TABLE OF CONTENTS

Correct citation for this publication:

Crawford, W.R. and J. R. Irvine. (2009). State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/022. vi + 121 p.

ABSTRACT

Despite continuing increases in overall global water temperatures, the waters off the Pacific coast of Canada were the coldest in 50 years, and the cooling extended far into the Pacific Ocean and south along the American coast. Near-shore temperatures dropped as well, as did temperature in deep waters of the Strait of Georgia. Only the surface temperatures in the Strait of Georgia remained at or above normal. This cooling is associated with weather patterns typical of La Niña and of the local cold phase of the Pacific Decadal Oscillation (PDO).

Surface phytoplankton and zooplankton concentrations were the highest in a decade of observations across the Gulf of Alaska in August and September 2008. The cause is as-yet uncertain, but injection of iron by winds or currents is suspected (Iron is a limiting nutrient in this region), along with higher levels of nitrate and silicate in spring. Ship-based sampling for phytoplankton in Juan de Fuca Strait revealed high near-surface concentrations in early September. Deep-sea and coastal zooplankton populations continued their recent shift to cold-water species and delayed spring blooms.

In the Gulf of Alaska, the ocean mixed-layer depth was relatively deep in early 2008, and surface oxygen concentrations were relatively high in early 2009. However, oxygen concentrations have generally declined in deep waters along the continental slope over the past several decades. A sudden decline in bottom-water oxygen concentration in 2008 on the continental shelf was likely due to denser water with naturally low oxygen levels moving up onto the shelf in this year, rather due to anomalous winds and currents. This oxygen drop may have been a factor in the movement of some groundfish species to shallower depths in 2008.

Cool marine conditions generally improve marine survival for salmon. However, despite relatively cool ocean conditions in 2007 and 2008, many BC populations remain depressed due to low numbers of brood-year spawners, partially attributed to warm oceans in 2003 to 2005. Sockeye returns remain generally low coast-wide, with one notable exception being Okanagan sockeye that returned in record numbers in 2008. High pre-spawn mortality was observed for many Fraser River watershed sockeye populations in 2008, and river entry of returning adults was generally early. Coho populations in southern BC remain extremely depressed, while northern coho populations have improved. For chinook, the situation is somewhat reversed – northern populations continue to decline while the status of southern chinook is highly variable.

Classification of salmon marine survival expectations based on a "weight of indicators" approach continues to show promise. In general, survivals of coho and sockeye that went to sea in 2008 are predicted to be at average- to above-average levels, meaning improved coho returns in 2009, and sockeye in 2010, relative to brood year strengths. One possible exception is Strait of Georgia coho.

Herring biomass has declined recently for all five major BC stocks. In the Georgia Basin where herring biomass was at record high levels earlier this century, the biomass declined

almost to the fishery-closure limit in 2008. Three other Canadian herring stocks were at or below the fishing limit. Eulachon populations remain depressed. Although there was no wide-scale hake survey in 2008, their numbers on the BC continental shelf, particularly on the traditional fishing grounds around La Pérouse bank, appear to have been very low, continuing a trend that began developing around 2003-04. Smooth pink shrimp and English sole along the west coast of Vancouver Island increased in numbers in 2008.

For many of our fish species including salmon, Pacific Ocean conditions have been improving since the extremely poor year of 2005. Cool water generated bottom-up changes to the food web that have contributed to improving marine survival for many juvenile fish. Linkages between ocean conditions and fish survival are not completely understood and additional exploration of existing data is warranted.

RÉSUMÉ

Les eaux au large de la côte canadienne du Pacifique étaient les plus froides en 50 ans, et ce refroidissement s'étendait loin dans l'océan Pacifique et au sud le long de la côte américaine. Les températures près des côtes ont aussi baissées, de même que la température des eaux profondes du détroit de Géorgie. Seules les températures de surface dans le détroit de Géorgie sont restées près ou au-dessus de la normale. Ce refroidissement est associé aux conditions météorologiques typiques de La Niña et de la phase froide locale de l'oscillation décennale du Pacifique (ODP).

Les concentrations de phytoplancton et de zooplancton dans les eaux de surface du golfe de l'Alaska étaient, selon une décennie d'observation, plus élevées que jamais en août et en septembre 2008. On n'en connaît pas encore la cause, mais on pense que ce pourrait être dû à une injection de fer par les vents ou par les courants (le fer est un élément nutritif limitant dans cette région), ainsi qu'à des niveaux plus élevés de nitrate et de silicate au printemps. Un échantillonnage à bord de navire du phytoplancton dans le détroit de Juan de Fuca a indiqué de fortes concentrations dans les eaux de surface au début de septembre. Les populations de zooplancton côtières et du large tendent de plus en plus vers les espèces d'eau froide et vers une prolifération printanière retardée. Dans le golfe de l'Alaska, la couche mélangée océanique était relativement profonde au début de 2008 et les concentrations d'oxygène de surface étaient relativement élevées au début de 2009. Cependant, au cours des dernières décennies, les concentrations d'oxygène ont en général diminué dans les eaux profondes, le long de la pente continentale. Il est probable que le déclin soudain en 2008 de la concentration d'oxygène dans les eaux de fond du plateau continental était dû à une remontée d'eau plus dense ayant une faible teneur en oxygène plutôt qu'à une baisse d'oxygène d'une masse d'eau particulière. Cette baisse d'oxygène a pu jouer un rôle dans le mouvement de certaines espèces de poisson de fond vers les eaux moins profondes en 2008.

En règle générale, des conditions marines froides améliorent le taux de survie marine du saumon. Cependant, en dépit des conditions océaniques plutôt froides en 2007 et en 2008, plusieurs populations de la C.-B. demeurent faibles en raison du faible nombre de géniteurs de l'année, en partie à cause des eaux océaniques chaudes de 2003 à 2005. Le retour des saumons rouges demeure généralement faible sur l'ensemble de la côte, sauf pour le saumon rouge de l'Okanagan qui retourna en nombre record en 2008. Les populations de saumon rouge du bassin hydrologique du fleuve Fraser ont subi en 2008 un fort taux de mortalité pendant la période précédant le frai et les adultes sont entrés dans le fleuve généralement tôt. Les populations de saumon coho du sud de la C.-B. restent très faibles,

alors que les populations du nord se sont améliorées. La situation est d'une certaine façon renversée pour le saumon quinnat - les populations du nord continuent leur déclin alors que l'état du saumon quinnat du sud est fortement variable.

La classification des prédictions du taux de survie marin du saumon selon l'approche du «poids des indices» se montre prometteuse. En général, on prédit que le taux de survie du saumon coho et du saumon rouge qui sont allés en mer en 2008 sera moyen ou supérieur à la moyenne, ce qui suggère des retours améliorés du saumon coho en 2009 et du saumon rouge en 2010, par rapport à l'effectif de l'année d'éclosion. Une exception pourrait être le saumon coho du détroit de Géorgie. La biomasse des cinq stocks importants de hareng de la C.-B. a récemment diminué. Dans le bassin de Géorgie où la biomasse de hareng était à un niveau record au début du siècle, la biomasse a diminué en 2008 à un niveau près de celui de la limite de fermeture de pêche. Trois autres stocks canadiens de hareng se situaient à la limite de pêche ou au-dessous. Les populations d'eulakane demeurent faibles. Bien qu'il n'y ait eu aucun relevé de merlu à grande échelle en 2008, leur nombre sur le plateau continental de la C.-B. semble avoir été très bas, surtout sur les lieux traditionnels de pêche près du banc La Perouse; cette tendance se maintient depuis environ 2003-2004. Le nombre de crevettes roses et de soles anglaises le long de la côte ouest de l'île de Vancouver a augmenté en 2008.

Pour nombre de nos espèces de poissons, dont le saumon, les conditions de l'océan Pacifique se sont améliorées depuis l'année extrêmement mauvaise de 2005. L'eau froide a entraîné un contrôle ascendant du réseau trophique, ce qui a mené à l'amélioration du taux de survie marine pour plusieurs poissons juvéniles. On ne comprend pas pleinement les liens entre les conditions océaniques et le taux de survie des poissons et une étude plus approfondie des données existantes s'avère nécessaire.

INTRODUCTION

This report is the tenth in an annual series updating the state of physical, biological, and selected fishery resources of Canadian Pacific marine ecosystems. Canadian Pacific marine waters lie in a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions, and experience strong seasonality and considerable freshwater influence. Variability is closely coupled with events and conditions throughout the tropical and North Pacific Ocean, experiencing frequent El Niño and La Niña events particularly over the past decade. The region supports important resident and migratory populations of invertebrates, groundfish and pelagic fishes, marine mammals and seabirds. Monitoring the physical and biological oceanographic conditions and fishery resources of the Pacific Region is done semi-regularly by a number of government departments, to understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. Support for these programs is provided by Fisheries and Oceans Canada, Environment Canada, and various other agencies.

About 50 scientists as part of the Fisheries Oceanography Working Group (FOWG) met at the Institute of Ocean Sciences (IOS) in Sidney, BC on 17-18 February 2009 for presentations on the state of the ocean and its marine life in 2008 and early 2009. The meeting was chaired by Jim Irvine and Bill Crawford, both of Fisheries and Oceans Canada. Bill and Jim subsequently produced this report based on contributions by participants. A new contribution this year is a summary of a counterpart report by American scientists on ocean and marine life in Alaskan waters.

Assessment highlights in the format of top stories from this year's meeting are provided on the next pages. The agenda for this meeting is in Appendix 1. The list of participants is in Appendix 2 and detailed contributions by participants are found in Appendix 3.

This report and others dating back to 1999 can be found at:

English: http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm

French: http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_f.htm

ASSESSMENT HIGHLIGHTS

TOP STORIES OF 2008

Coolest ocean in 50 years in the northeast Pacific

Waters off the Pacific coast of Canada were the coldest in 50 years of observations, and the cooling extended far into the Pacific Ocean and south along the American coast. The blue and green regions of relatively cold waters in Figure 1 dominated the central and northeast Pacific Ocean. Global warming prevailed almost everywhere else. Warmer temperatures covered almost the entire globe, with highest warming in the Arctic and northern Europe and Asia.

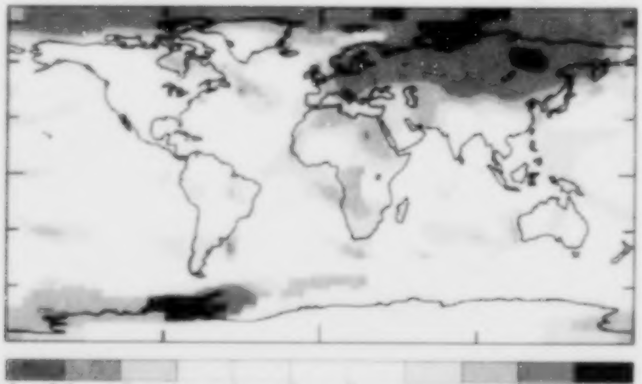
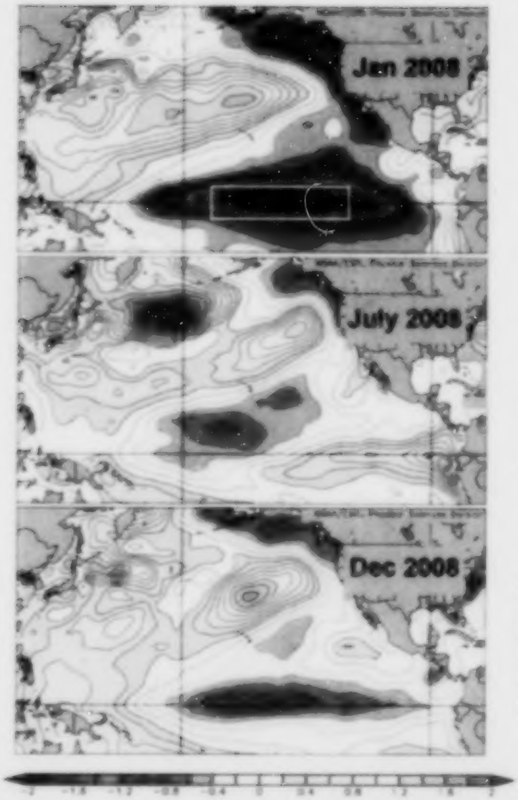


Figure 1. Annual surface temperature anomaly for 2008 (°C) relative to 1961 to 1991. Image provided by Goddard Institute for Space Studies http://data.giss.nasa.gov/gistemp/2008

We attribute this cool northeast Pacific Ocean to La Niña and to a cool phase of the Pacific Decadal Oscillation (PDO) that dominated through 2008. La Niña events are defined by ocean temperatures in the white-bordered box of Figure 2, top panel. Relatively cool oceans on the Equator normally bring cool winds and waters to the northeast Pacific in winter. This is just what happened through the winter of 2007 to 2008, when the Aleutian Low Pressure system strengthened and moved eastward into the northern Gulf of Alaska, bringing cool westerly winds across the Gulf of Alaska, rather than warmer "Hawaiian" air masses of typical winters that blow from the southeast. This pattern repeated in late 2008 although with weaker winds, and the cool waters persisted off the west coast well into spring 2009.

The images above reveal only sea surface temperatures; for a look at temperature below the surface we rely on ship-based measurements and autonomous floats. Ship-based observations are provided by scientists of Fisheries and Oceans Canada who have measured ocean temperature for more than 50 years in the northeast Pacific Ocean along Line P, a set of stations extending almost 1500 km west from Vancouver Island as shown in Figure 3a. Figure 3b reveals the extent of cooling in the top 500 metres in June 2008 along this set of ocean climate stations. Surface temperatures reached almost 4 degrees Celsius below normal and the cooling extended 100s of metres down into these waters. Only ocean surface cooling and horizontal transport of cool water into this region in winter could have dropped temperatures so far. Figure 3c compares the cool waters of 2008 to all previous years along Line P. Only in 1969 was the temperature close to the record cooling in 2008.



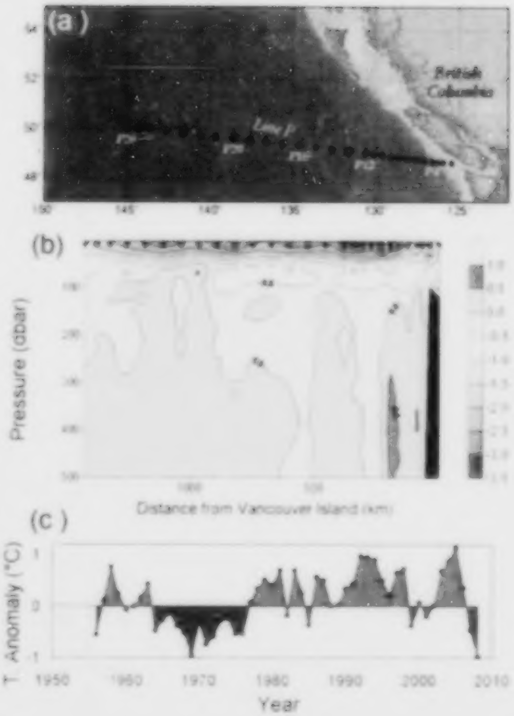
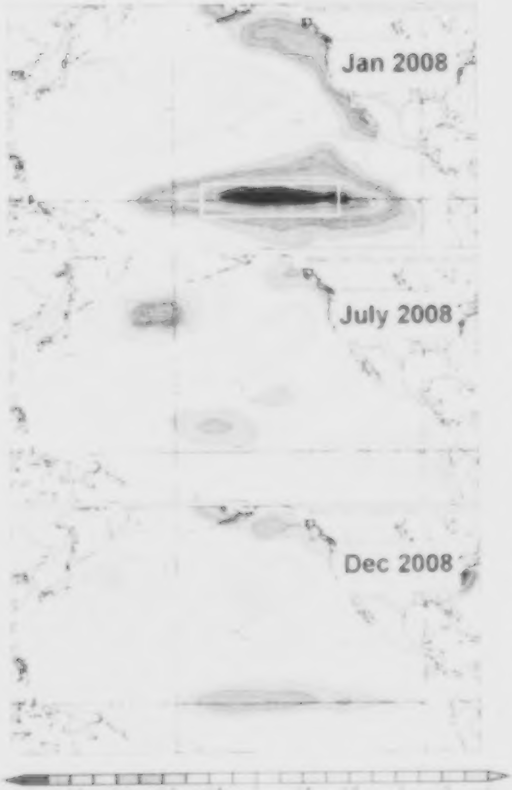


Figure 2 (left). Ocean surface temperature anomalies (°C) in tropical and North Pacific in January, July and December 2008. Temperature scale is at bottom of the figure. The white box outlines the Niño 3.4 region whose temperatures determine the official strength of El Niño and La Niña events. Reference years are 1968 to 1998. Note the very negative anomalies there in January 2008, indicating a strong La Niña. Source: NOAA Environmental Studies Research Lab., Physical Sciences Division.

Figure 3 (right).
(a) Map of ocean-climate stations along Line P. DFO scientists lead multi-disciplinary research cruises along these stations three times per year, accompanied by academics from all over North America. Intensive sampling of water properties takes place at the five labelled stations in this figure.
(b) Plots of temperature anomaly along Line P in June 2008. The pressure level determines the depth below surface (1 dbar = 1 metre of depth). Black region at right is the Vancouver Island continental shelf.
(c) Graph of annual-average temperature anomalies along Line P at 10 to 50 metres below ocean surface. The last point on the right shows 2008 to have the coldest-ever temperature of the entire series, although only 0.02 °C cooler than in 1969. Warmest-ever temperature was in 2005, only three years earlier. This decline of 2 degrees Celsius in only 3 years is by far the greatest decline observed, and is attributed to a major shift in winds and currents in the Gulf of Alaska.



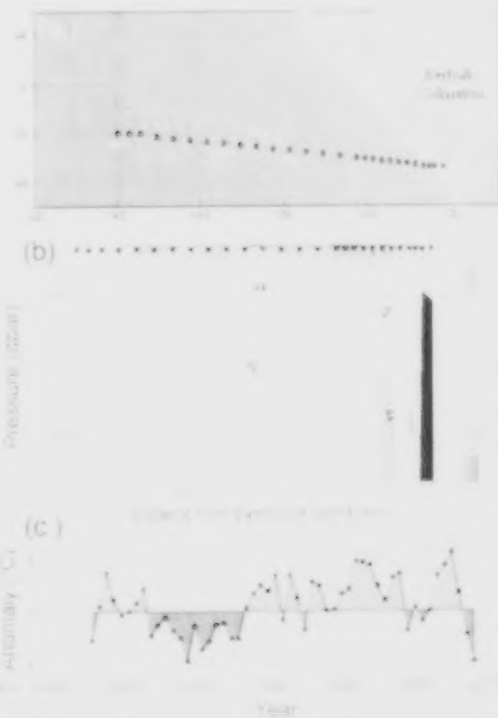


Figure 2 (left). Ocean surface temperature anomalies (°C) in tropical and North Pacific in January, July and December 2008. Temperature scale is at bottom of the figure. The white box outlines the Niño 3.4 region whose temperatures determine the official strength of El Niño and La Niña events. Reference years are 1968 to 1998. Note the very negative anomalies there in January 2008, indicating a strong La Niña. Source: NOAA Environmental Studies Research Lab., Physical Sciences Division.

Figure 3 (right).
(a) Map of ocean-climate stations along Line P. DFO scientists lead multi-disciplinary research cruises along these stations three times per year, accompanied by academics from all over North America. Intensive sampling of water properties takes place at the five labelled stations in this figure.
(b) Plots of temperature anomaly along Line P in June 2008. The pressure level determines the depth below surface (1 dbar = 1 metre of depth). Black region at right is the Vancouver Island continental shelf.
(c) Graph of annual-average temperature anomalies along Line P at 10 to 50 metres below ocean surface. The last point on the right shows 2008 to have the coldest-ever temperature of the entire series, although only 0.02 °C cooler than in 1969. Warmest-ever temperature was in 2005, only three years earlier. This decline of 2 degrees Celsius in only 3 years is by far the greatest decline observed, and is attributed to a major shift in winds and currents in the Gulf of Alaska.

Record high plankton numbers in the Gulf of Alaska

Phytoplankton and zooplankton concentrations in deep-sea waters in August 2008 were by far the highest observed in any summer in the past 10 years, and might have enriched the food supply for salmon in these waters. Some of these salmon will return to west coast rivers in 2009.

Two American satellites, SeaWiFS and MODIS, determine the concentration of chlorophyll at the ocean surface based on their observations of ocean colour. Chlorophyll is an indicator of phytoplankton biomass, so from these measurements we can estimate the concentration of phytoplankton in the ocean, Although clouds obscure the view over the Gulf of Alaska on most days, a monthly composite of the best observations provides distribution maps of this microscopic plant life at the ocean surface. Figure 4 below presents an image for August 2008, revealing that the entire ocean surface of the Gulf of Alaska was filled with phytoplankton.

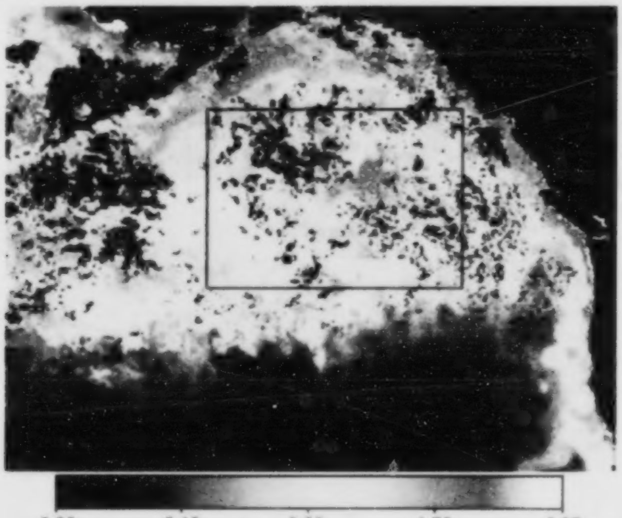


Figure 4. Chlorophyll concentration in the Gulf of Alaska in August 2008, based on observations by NASA MODIS satellite. Colour bar below the figure presents chlorophyll scale in mg m-3. White regions near the coast hold highest concentrations, due to local nutrient enrichment. Red and yellow colours reveal waters with abnormally high levels for August in mid-ocean. The black box outlines the regions over which a time series of chlorophyll concentrations is plotted in the next figure.

The time series of Figure 5 below shows month-by-month anomalies of chlorophyll at the ocean surface, based on the type of data plotted above over the Gulf of Alaska. The concentrations of August and September 2008 rose well above the levels found in any previous month. Growth of phytoplankton in this gulf in summer is normally limited by lack of iron. Although we suspect enhanced iron supply as a likely cause of the phytoplankton bloom, its source is uncertain. Several volcanoes erupted in summer 2008 in the Aleutian Islands, so volcanic dust is a possible source of iron, but it is not easily spread over the entire gulf by winds alone. Unusual currents in the summer of 2008, which could have transported either volcanic or oceanic iron from the Alaskan Peninsula into mid-gulf, are described in the report on flow in the North Pacific Current.

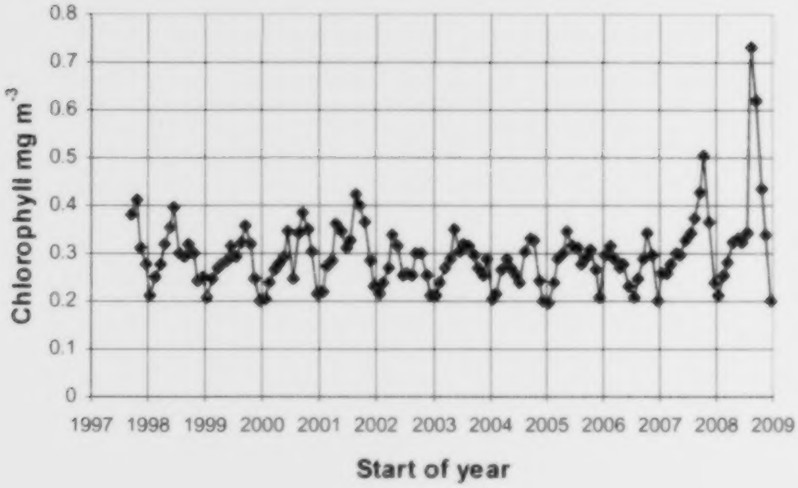


Figure 5. Time series of monthly chlorophyll in the Gulf of Alaska averaged over the black box shown in Figure 4. Data are provided by NASA satellites SeaWiFS and MODIS. Observations in 2008 are by MODIS sensor on Aqua satellite. Data provided by: http://oceancolor.gsfc.nasa.gov/

Zooplankton concentrations rose to the highest levels recorded in ten years of observations, as revealed in Figure 6. Zooplankton are the smallest animals in the ocean and many feed on phytoplankton, so it is not surprising to see the highest recorded concentrations of zooplankton in the Gulf of Alaska in August 2008 during the phytoplankton bloom. Zooplankton samples plotted in Figure 6 below were collected from continuous plankton recorders (CPR) towed behind commercial vessels, as part of a program now ten years old. The blue trace for 2008 in Figure 6 reveals the clear maximum in zooplankton concentrations for August, coinciding with the phytoplankton maximum. *Neocalanus cristatus* (an exceptionally large calanoid copepod type of zooplankton) had highest summer abundances recorded in the CPR time series in 2008, and this was augmented by later occurrences of *N. plumchrus* as well as *Calanus pacificus* being present in reasonable numbers.

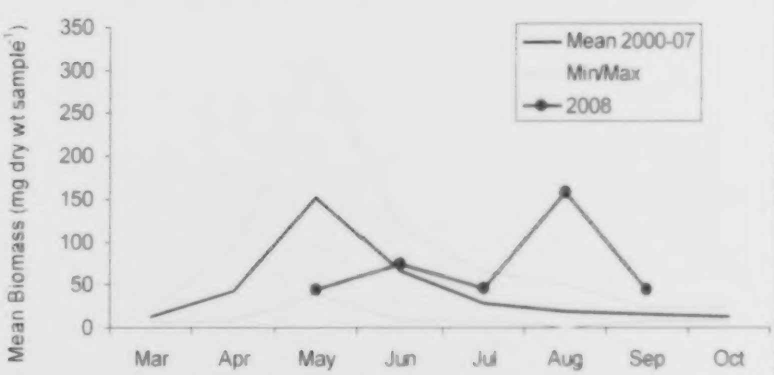


Figure 6. Mean monthly biomass for 2008, together with monthly mean, minimum and maximum mesozooplankton biomass (2000-07) in mg dry weight per sample (~3m^3) from Continuous Plankton Recorder (CPR) sampling (which occurs approximately monthly 6-9 times p.a. between March and October) in the off-shore Gulf of Alaska area. Data for summer 2008 are preliminary.

Stronger flow in North Pacific Current

Stronger winter westerly winds in the winter of 2006-07 and 2007-08, combined with a more intense Aleutian Low Pressure System in the northern Gulf of Alaska, are the likely causes of a very strong North Pacific Current all through 2008, peaking in summer 2008. Figure 7 below shows the classical view of ocean surface currents of the Gulf of Alaska and Figure 8 presents the time series of the strength of these currents since 2001, based on observations by Argo autonomous floats in the gulf.

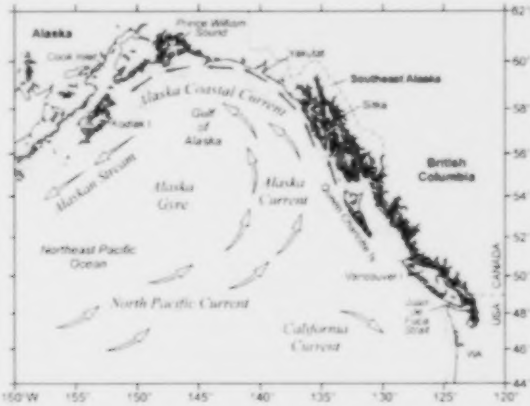


Figure 7. The North Pacific Current flows eastward across the middle of the Gulf of Alaska, splitting near North America into the northward-flowing Alaska Current and the southward-flowing California Current. Stronger eddies off Kodiak Island combined with a more easterly and stronger North Pacific Current might be factor in providing sufficient iron into the middle of the gulf for the plankton bloom of 2008 summer.

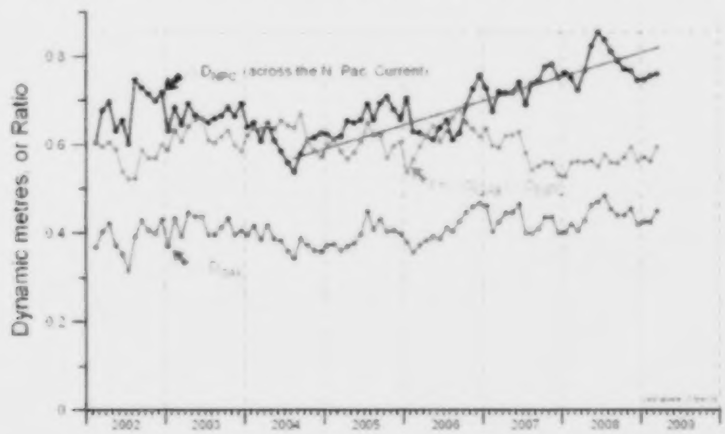


Figure 8. Time series of ocean current strength in the Gulf of Alaska, based on dynamic height calculated from temperature and salinity measured by Argo floats.

The North Pacific Current reached maximum strength in May to August of 2008. The red line presents the fraction of eastward flowing North Pacific Current waters that continue into the Alaskan Stream. Remaining water flows into the California Current.

Spreading hypoxia in deep waters along the west coast

Oxygen levels are declining in waters found 100 to 500 metres below the ocean surface (Figure 9), based on time-series measurements of at least 25 years collected in the mid gulf of Alaska at Ocean Station P, and along the Pacific coast of southern California (S CA), southern BC (WCVI), and the west coast of Queen Charlotte Islands in northern BC (WCQCI). Rates of decline exceed 1% per year in the 200 to 300 metre range in coastal waters that presently contain 50 to 130 μM oxygen.

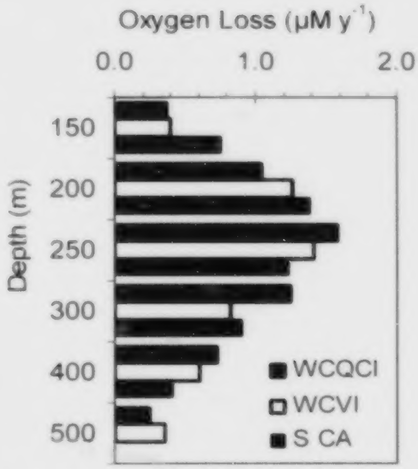


Figure 9. Rates of oxygen loss at three stations along the Pacific coast of North America.

Many other studies have remarked on the loss of oxygen in sub-surface waters of the subarctic Pacific, identifying the cause as weakening winter ventilation off the Asian coast due to a freshening and perhaps warming of the mixed layer. The warming trend is not as assured as freshening because of the large annual cycle. As oxygen diminishes in coastal waters, there must be impacts on biological communities since all animals require oxygen. Along the Oregon coast, low oxygen events have caused fish and crab kills at the ocean bottom within the last several years, events not observed in the previous century.

Oxygen concentrations in bottom waters of the BC continental shelf dropped markedly in 2008, compared to 2006. This finding was determined from instruments attached to trawl nets during research cruises in these two years. (No sampling took place in 2007. Oxygen sensors were not available prior to 2006). Figure 10 presents these observations along the west coast of Vancouver Island in May and June of 2006 and 2008. The red symbols, representing 2008 samples, clearly show lower oxygen concentrations than found in 2006. However, a study of the water density of these samples reveals that the difference is mainly due to denser water with lower oxygen content moving to shallower depths in 2008, due to anomalous winds and ocean currents.

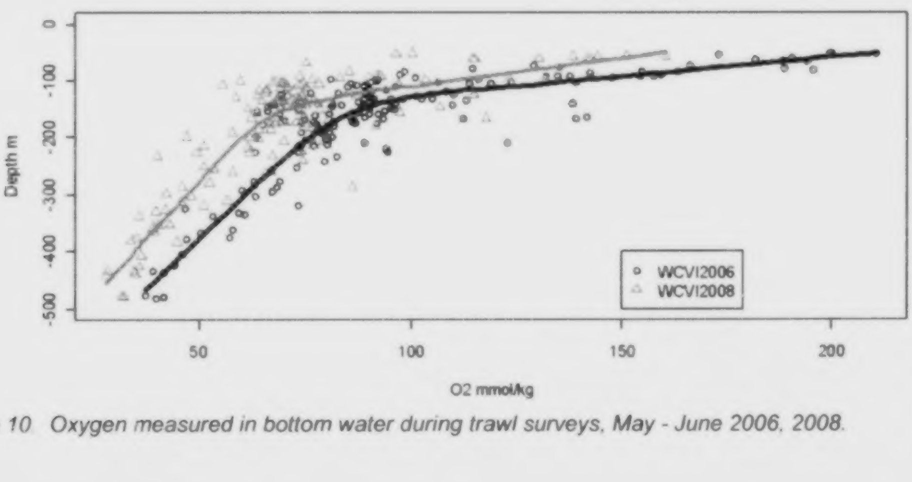


Figure 10. Oxygen measured in bottom water during trawl surveys, May - June 2006, 2008.

High survival for juvenile salmon, seabirds and sablefish off Vancouver Island

Almost 30 years of regular sampling of zooplankton off Vancouver Island shows that we can predict juvenile survival rates of key marine species based on these data. Measurements in 2008 show these survival rates were high and provide good news for fisheries several years from now. These species include juvenile salmon and sablefish in southern BC, and seabirds on Triangle Island.

Although there are more than 50 species of zooplankton that are counted in samples every year, those that thrive best in coastal waters fall mainly into "warm" and "cool" groups, named for the relative temperature of water they prefer. It is suspected that 'cool water' zooplankton are better fish food (larger individual body size and much higher energy content).

Because much of the year-to-year variability of marine survival rate of harvested fish species occurs at early life stages (for salmon, in their first year after ocean entry), observations of zooplankton anomalies provide a useful index of health and survival of juvenile coho salmon along the outer coast, sablefish recruitment, and seabird reproductive success on Triangle Island off northern Vancouver Island. Interannual variability of all of these time series can be described as 'cool-and-productive' or 'warm-and-unproductive'.

Figure 11 presents this index, updated for 2008. Note that 2008 was among the four most "cool and productive" years. Survival of seabird chicks was the highest ever in 2008 on Triangle Island. We must wait a few years to see if coho and sablefish juveniles thrived as successfully as seabirds. However, other observations noted below also suggest high survival of juvenile salmon.

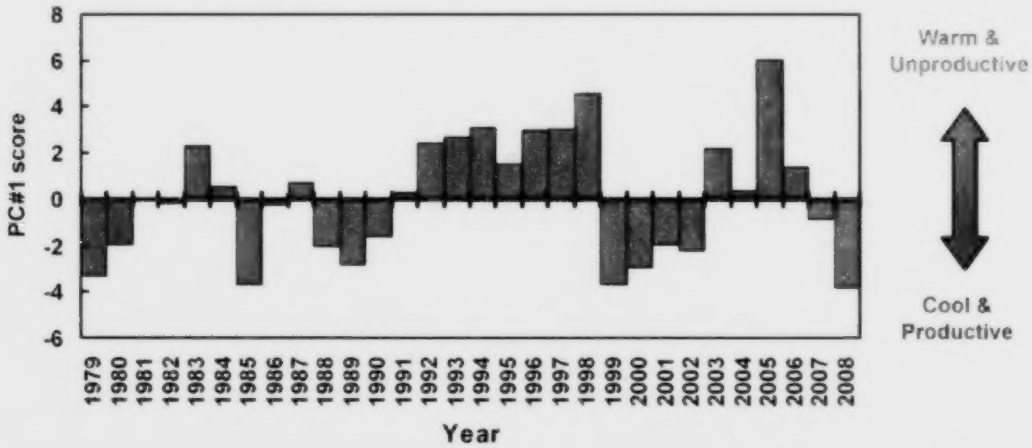


Figure 11. Time series of scores of the marine survival index in coastal waters off Vancouver Island.

Scientists of Fisheries and Ocean Canada also rely on direct observations of juvenile salmon numbers and size to determine future returns. The June-July 2008 catches-per-unit-effort of juvenile Chinook, sockeye and chum salmon off the west coast of Vancouver Island were the highest on record since 1998 by nearly a factor of ten, and the third highest for juvenile coho salmon. This suggests that early marine survival was consistently high for all the species of

salmon in 2008 in this area. Thus, adult returns are expected to be high in 2009 for coho salmon, in 2010-2011 for Chinook and sockeye salmon, and in 2011 for chum salmon.

However, the predictions for Chinook salmon are only applicable to Columbia River spring Chinook, as these are the stocks normally caught during the June-July surveys off the west coast of Vancouver Island.

In contrast to 2008, catch-per-unit effort of juvenile salmon in 2005 off the west coast of Vancouver Island were generally the lowest on record for most species, suggesting poor marine survival for the smolts that migrated to sea that year. This may explain the poor returns of several stocks of salmon in recent years.

Sardine, herring and eulachon are down; shrimp are in slow recovery

Herring:

Herring abundance on the west coast of Vancouver Island is at an historically low level following a decade long series of poor recruitments. However, recruitment may improve over the next few years as a result of reduced predator levels. Herring in the Hecate Strait area consist of migratory stocks from the Queen Charlotte Islands, Prince Rupert and Central coast areas. For the past decade, recruitment and abundance of the Queen Charlotte Islands stock has been low while recruitment and abundance of the Prince Rupert and Central Coast stocks have been average to good. Recruitment of the 2003 and 2005 year-classes was weak in all three areas resulting in slight declines over the past four years. Cooling ocean conditions since 2005, combined with a decrease in abundance of hake population, may result in an improvement in herring recruitment and stock abundance over the short term.

The abundance of Strait of Georgia herring in 2008 continued the decline that began in 2002 from the near-historic high levels of more than 100,000 tonnes. The declining trend in recruitment over the past five years will translate into reduced mature abundance levels over the next few years. Reduced hake abundance may result in improving recruitment and fall surveys of juvenile herring suggest an average recruitment in 2009 followed by a weaker year-class in 2010.

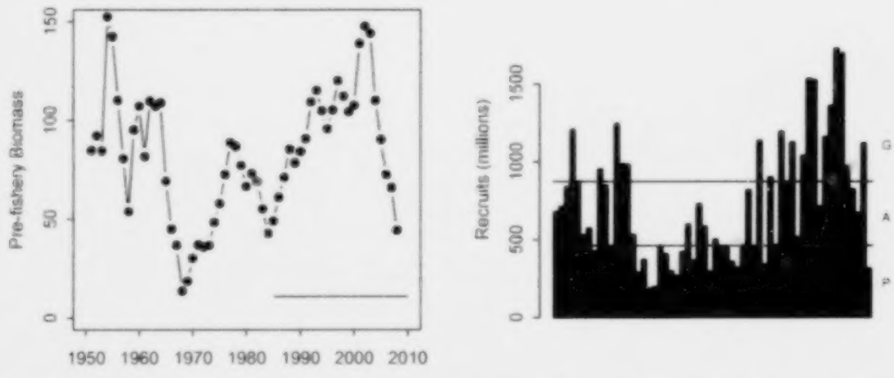


Figure 12. Pre-recruitment biomass and number of recruits of herring in Strait of Georgia stocks, one of five stocks monitored by Fisheries and Oceans Canada.

Sardine:
Sardines reappeared off the west coast of Vancouver Island in 1992. During the 1990s their distribution expanded northward from southern Vancouver Island through Hecate Strait to Dixon Entrance. In 2003 and 2004 the distribution of sardines in B.C. was limited to the inlets of Vancouver Island and offshore areas in the south. Warm conditions in 2004 to 2005 and a very strong 2003 year-class has resulted in widespread distribution of sardines throughout southern Hecate Strait and Queen Charlotte Sound since then.

Eulachon:
Eulachon abundances as evidenced from incidental capture in the shrimp research survey off the WCVI and egg and larval surveys in the Fraser River both indicate substantial decline in population size since the mid-1990s. Anecdotal information suggests the decline in eulachon has been coastwide throughout British Columbia and Washington implying a large scale oceanographic process impacting their survival. Recent data suggests that eulachon are at an historical low level of abundance in the Fraser River..

Smooth Pink Shrimp:
Bottom trawl surveys using a small-mesh net (targeting the smooth pink shrimp Pandalus jordani) have been conducted during May since 1973. The survey in 2008 found the biomass of Pandalus jordani shrimp off central Vancouver Island had increased from very low levels during 2004-2007, possibly as a result of colder ocean conditions when they were hatched in 2006; this population may be beginning to recover after warm conditions during mid-decade. Biomass of flatfish species also increased in 2008 after declines in 2006 and 2007. Some biomass changes, such as for spiny dogfish, English sole and Pacific hake in recent years, may be due to increased catches of adult fish rather than sub-adults during these research fisheries.

Marine species of Pacific Rim National Park Reserve

Pacific Rim National Park Reserve of Canada, located on the west coast of Vancouver Island between the towns of Tofino and Port Renfrew, has the mandate to monitor and report on the state of its ecological integrity of marine and terrestrial ecosystems within the Park bounds. Information is provided here for marine biota with more than 10 years of observations.

The overall abundance of Littleneck and Manila Clams changed little, but Butter Clams seem to show a general decline in the past 7 years. Some other species, however, displayed statistically significant trends. The overall density of the exotic Varnish Clam has increased 8-fold from mid 1990s, whereas no Varnish Clams were recorded in the Park in 1978. On the other hand the density of the Olympia Oyster has declined sharply over the past 10 years.

Regression analyses suggested that out of the six common species of seabirds for which Pacific Rim National Park has long-term data, four – Marbled Murrelet (Brachyramphus marmoratus), Surf Scoter (Melanitta perspicillata), Pelagic Cormorant (Phalacrocorax pelagicus) and Rhinoceros Auklet (Cerorhinca monocerata) – have declined or continue to decline as compared to mid 1990s. In at least three of the species that feed on pelagic forage fish and zooplankton (Marbled Murrelet, Pelagic Cormorant and Rhinoceros Auklet), the recorded numbers mirror biomass estimates for Pacific herring. Much of the decline seems to be associated with the collapse of local Pacific herring stocks.

Two larger Glaucous-winged Gull (Larus glaucescens) colonies in the Park – Florencia Island and Seabird Rocks – experienced steep population declines in late 1960s – early 1970 (although large data gaps make this assessment qualitative). It appears the Seabird Rock colony collapsed first, with many birds moving to Florencia Island, with the latter colony

succumbing to the agent of decline by 1975. The timing of the declines coincided with the coast-wide collapse of Pacific herring stocks in the 60s and 70s, due to overfishing.

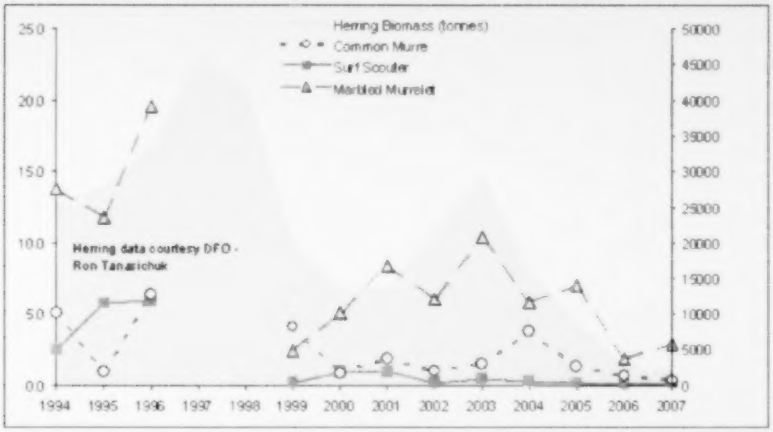


Figure 13. Trends in seabird numbers expressed as density per 1 km linear route contrasted against local Herring stocks (blue background). Red trends indicated species with statistically significant population declines. Blue trends refer to relatively stable populations within Park waters.

Grey whales (Eschrichtius robustus) are photographed and then individually identified using patterns of scratches, scars, and growths of barnacles and whale lice. Numbers fluctuate widely: 30 or more grey whales were observed in each of 1998, 2005 and 2006, whereas only 2 and 3 individuals were recorded in 2001 and 2007. In 2008, 46 individuals were recorded, which is the record count for the Park.

Variable sockeye returns, despite improving ocean survival

In each of five regions of BC and southeast Alaska, one or more sockeye runs are assessed with accurate and precise enumeration methods for adult returns and juvenile outmigrants, and are used as indicators of freshwater and marine survival and productivity for nearby stocks. Sockeye indicator stocks for four regions are described below. The return strength for stocks depends on both the brood year escapement (number of spawners) and survival conditions in both the freshwater and marine environment. If brood year escapements are below average returns generally will also be below average despite overall good survival conditions.

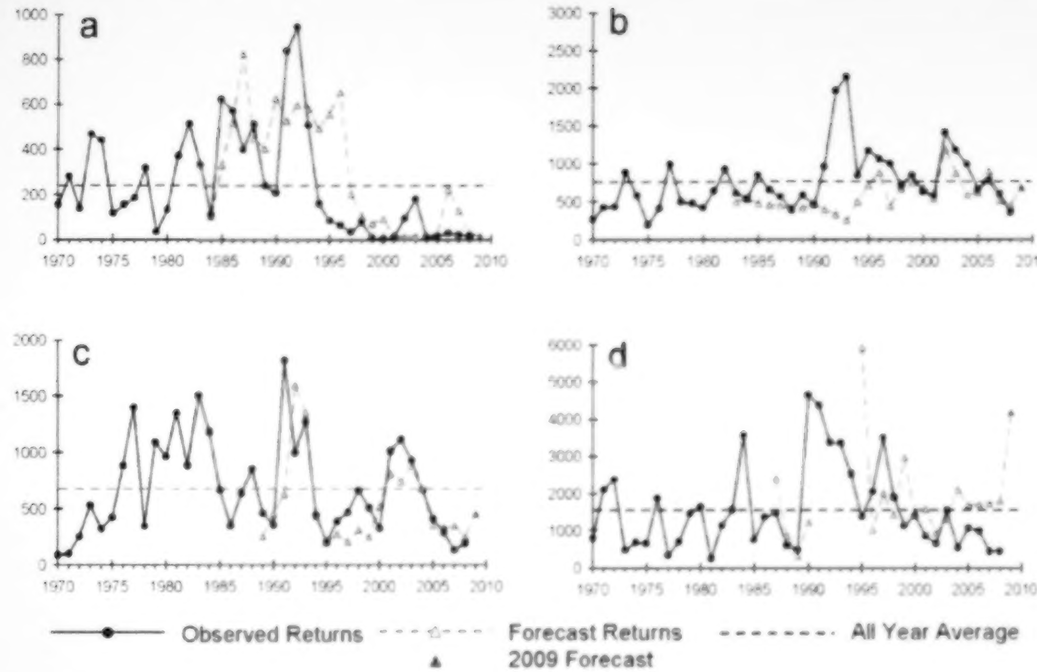


Figure 14. . Trends in the total returns and forecasts for British Columbia sockeye index stocks: (a) Nass, (b) Rivers and Smith's Inlet, (c) Barkley Sound sockeye salmon, d) Fraser River sockeye salmon. Y-axes represent returns in thousands of fish.

Barkley Sound sockeye on the west coast of Vancouver Island exhibit annual recruitment variations that alter abundance patterns by more than a factor of ten within intervals as short as 2-3 years (Figure 14c). Studies of these variations have supported the use of a simple two-state, "survival-stanza", model since 1988, whereby "La Niña-like" conditions (SST < 30 yr average during smolt migration, low northward transport, average to below average sea level) are associated with relatively high marine survival (5 %) and "El Niño-like" conditions (SST > 30 yr average, elevated sea level, high northward transport) with lower marine survival (2.5 %) of fish in their first year in the ocean. With the cool conditions of 2007-2008, and some observations of increased numbers of juvenile sockeye along the Vancouver Island West Coast, we anticipate increased marine survival that will permit a period of stock rebuilding for west coast Vancouver Island coho returning in 2008-2009 and sockeye returning in 2009-2010, but total returns are likely to remain sub-average until depressed escapements are rebuilt.

Rivers and Smith's Inlet sockeye (Figure 14b) supported one of the most valuable fisheries on the central coast of BC until severe stock declines in the early to mid-1990s forced their closure. Studies suggest that the steep decline and low returns of sockeye this region since the 1990s are due to persistently low marine survival. By contrast, a strong compensatory response of increased egg-to-fall-fry survival in freshwater (Smokehouse River, Canoe Creek, and Long Lake, accompanied major reductions in spawner abundance for the 1997-2001 and 2005-2006 brood years and buffered Smith's Inlet sockeye from even more severe declines. The depressed state of sockeye escapements in 2004-2005 and reduced smolt output in sea-entry years 2006 and 2007 suggest sub-average total returns to Smith's Inlet and Long Lake in 2009.

Nass River indicator stocks (Fig. 14a) declined from early-1990s highs, exhibited by all sockeye indicator stocks, but relative to more southerly stocks, have remained closer to their all-year average return values since the late 1990s.

For the Fraser River indicator stock (Chilko River sockeye), marine survival was low in recent years (1995 to 2009 return years) attributed to poorer ocean survival conditions in the corresponding smolt outmigration years (1993 to 2006). Ocean survival was particularly low for the 2007 return year (2005 smolt outmigration year). Ocean survival subsequently increased in the 2008 return year (2006 smolt outmigration year) and is also expected to further increase in subsequent return years due to improving ocean conditions. For Chilko in particular, well above average freshwater survival produced an unprecedented number of smolts in 2007 combined with improved marine survival conditions produced a high return forecast for 2009 for this stock (Fig. 14d). Other Fraser stocks have generally exhibited average to above average brood year escapements for 2009 returns (with some exceptions) and, therefore, given ocean positive ocean conditions during their ocean entry year (2006), returns are expected to generally be average to above average.

Below average coho returns despite improving ocean survival

Coho salmon are similar to sockeye in that northern populations tend to be doing better than populations to the south (Fig. 15). Coho from Alaska and northern BC exhibited similarly variable survivals with no significant trend. Alaska coho survived at consistently higher rates than those from northern BC. Coho from the west coast of Vancouver Island, Strait of Georgia, and Puget Sound experienced significant declines over the time series; Puget Sound coho survived at higher rates than SOG coho. The return strength for stocks depends on both the survival conditions and brood year escapements (number of spawners). If brood year escapements are below average returns generally will also be below average despite overall good survival conditions.

Various physical and biological environmental variables were significantly associated with coho survival. Relatively good survivals are forecast for BC coho returning in 2009 – one possible exception is the Strait of Georgia that experienced mixed signals. However, it is important to realize that good survivals do not necessarily mean good returns. Coho returning in 2009 are the progeny of coho that went to sea in the spring of 2005, many of which experienced extremely low survivals.

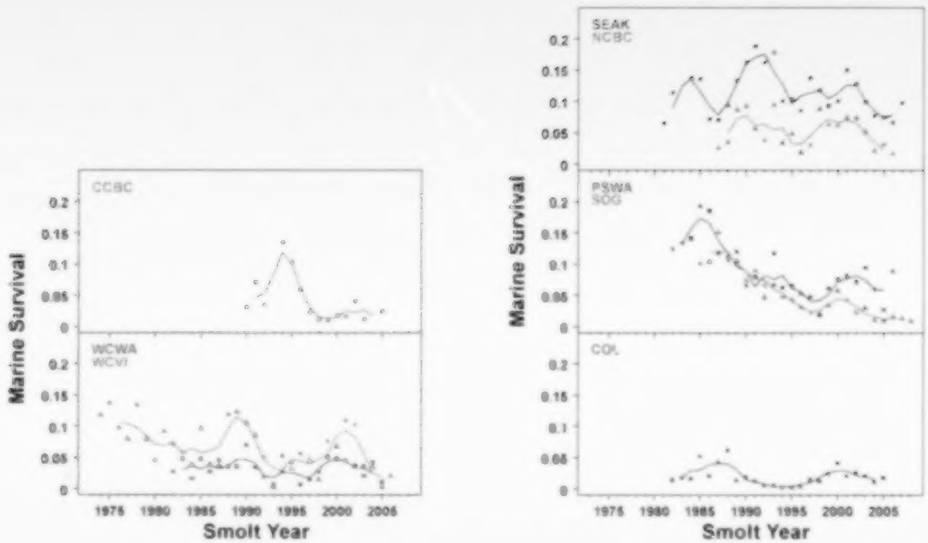


Fig. 15. Mean annual marine survivals (3-year moving averages) for representative coho salmon populations from southeast Alaska (SEAK), the north coast of BC (NCBC), central coast of BC (CCBC), Strait of Georgia (SOG), Puget Sound Washington (PSWA), west coast of Vancouver Island (WCVI), west coast of Washington State (WCWA), and Columbia River watershed (COL).

Indicators for 2009 salmon returns in the Georgia Basin

Salmon have the most complex and vulnerable life cycle of any marine species on our coast. From eggs hatching far up the Fraser or other rivers, to their passage as juveniles all along the Inside Passage and out to the Aleutians, into the deep-sea waters of the Gulf of Alaska and finally back to their native stream bed to spawn, they pass millions of humans and other predators. Several approaches are used in the Pacific Region to forecast salmon returns and these include stock-recruitment approaches, the use of indicators (biological or physical oceanographic indicators) of salmon ocean survival conditions, and juvenile abundances observed in the Strait of Georgia and Pacific Ocean.

Fraser River Sockeye Forecasts (Stock-Recruitment Data)

Sockeye returns are particularly difficult to forecast due to their long migrations routes through the river and ocean, and our lack of specific information on their success at each point of their journey. Predictions for numbers of each Fraser sockeye stock returning to the river are typically based on the empirical relationship between stock size (adult spawners or juveniles) and consequent recruitment. In most cases, including ocean environmental variables as covariates in stock-recruit models has not improved forecast performance. Therefore, forecasts of return abundances generally assume average marine survival conditions. If ocean conditions are below or above average, or if juvenile size at ocean entry deviates from average, then this will result in the over- or under-estimation of actual returns.

Fraser sockeye return forecasts are presented in tables as slices through a cumulative probability distribution at five probability levels: 10%, 25%, 50%, 75%, and 90% (see Table 1 for 2009 forecast for example). Probability distributions are used to capture uncertainty in forecasts using Bayesian statistics. They are presented as the probability of exceeding the specific return forecast; therefore, the smallest percentage presented (10%) has the largest associated return forecast and as the probability percentage increases, the return forecast decreases.

	Probability of Exceeding Specified Run Sizes				
Sockeye run timing group	10%	25%	50%	75%	90%
Early Stuart	645,000	426,000	255,000	165,000	107,000
Early Summer	2,284,000	1,338,000	739,000	443,000	264,000
Summer	31,813,000	16,071,000	8,677,000	4,914,000	2,858,000
Late	2,875,000	1,616,000	907,000	517,000	327,000
Total	37,617,000	19,451,000	10,578,001	6,039,001	3,556,001

Table 1. Pre-season sockeye forecasts for 2009 by run timing group and probability.

In recent years, the forecast process has included recommendations to use more (>50%) or less conservative (<50%) probability levels depending on indications of, respectively, poorer- or better-than-average ocean conditions. To provide some indication of marine survival conditions for Fraser River sockeye salmon, a compilation of ocean survival indicators for salmon are used to qualitatively compare relative ocean survival conditions from 1998 to 2007 (Table 2). The methodology for ranking individual indicators is based on W.T. Peterson's approach (U.S. Northwest Fisheries Sciences Centre, National Ocean and Atmospheric Agency). For the 2009 forecast (Table 1), ocean conditions using the indicator approach have improved relative to the two previous years with both biological and oceanographic conditions above average for salmon survival (Table 2). Therefore for 2009, the 50% probability forecast is recommended for pre-season planning purposes (with the exception of Early Stuart at the 75% probability level due to this stock's overall lower productivity in recent years).

Currently, the suite of ocean indicators explored only partially tracks Chilko marine survival (marine survival indicator system for Fraser sockeye stocks) (Table 2). This suggests that more ocean indicators need to be explored and/or developed to improve forecasting methodology. The prediction in Figure 14c indicates that over 4 million adults are expected to return, based on the record high number of smolts that entered the ocean in 2007.

The suite of indicators in Table 2 provided a strong indication of the very poor ocean survival conditions experienced by Fraser sockeye in 2005 (poor returns in 2007). Therefore, it may be most useful currently in providing an indication of very low marine survival rather than high survival. We will continue to explore the utility of this approach.

(RETURN YEAR)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Chilko Marine Survival	G	Y	G	G	R	Y	G	R	Y	NA
Ocean Indices										
1 PDO (Jan-March average)	R	G	G	R	G	R	R	R	Y	Y
2 ALPI	R	G	Y	R	R	R	R	Y	G	G
Physical Conditions										
3 SST (Entrance Island)	R	G	G	G	G	R	R	R	Y	Y
4 SST (Pine Island)	R	G	G	G	Y	R	R	R	Y	G
5 Upwelling index (48°N)	G	G	R	Y	G	R	Y	R	Y	G
6 Spring transition timing (48°N)	G	G	Y	Y	G	Y	Y	R	Y	Y
Biological Conditions										
7 Southern Copepods (SVI)	R	G	Y	G	G	R	Y	R	R	G
8 Boreal Shelf Copepods (SVI)	R	G	G	Y	G	Y	R	R	R	G
9 Southern Copepods (NVI)	R	G	G	G	Y	R	Y	R	R	G
10 Boreal Shelf Copepods (NVI)	Y	G	G	R	G	R	R	R	Y	G

Table 2. Indicators of ocean conditions from 1998 to 2007. For each indicator, annual estimates were ranked across all years from 1 to 10 from best to worst salmon ocean survival conditions. Green (G): ranks 1 to 4; yellow (Y): ranks 5 to 7; red (R): ranks 7 to 10.

The presence of many Green boxes in 2009 in Table 2 is an encouraging sign for Fraser River sockeye fishing after several years of low returns.

Salmon Forecasts (Juvenile Data in the Strait of Georgia)

Research fisheries in the Strait of Georgia capture small numbers of juvenile salmon at several times each year using standard trawl methods and locations. From year-to-year changes in these catches scientists are able to provide insight into future returns of these species. In recent years adult returns are forecasted using CPUE of juvenile salmon in July midwater trawl surveys and use the red/amber/green system. The ability to forecast returns for individual stocks has improved in recent years with the development of DNA methods that can be used to identify the stock of juvenile salmon caught in the marine environment.

Sockeye:

Juvenile sockeye catches are generally quite low in Strait of Georgia and coastal surveys, therefore, no quantitative forecasts based on juvenile abundances in the ocean have been possible. Some preliminary DNA samples have been analyzed for juvenile sockeye collected in July, September and November trawl surveys. In July, catches of juvenile sockeye were generally confined to Howe Sound, with small catches in the northern Strait of Georgia and in the Gulf Islands. By September, catches were primarily along the mainland coast up to Malaspina Strait. By November, no sockeye were found in Howe Sound, but large numbers were still present in the Gulf Islands region. DNA analysis of these fish showed that an overwhelming percentage (97%) of the sockeye in both the Strait of Georgia and in the Gulf Islands were of Harrison River origin. Harrison River sockeye are unusual along the west coast in that they migrate to sea as fry rather than spending a winter in freshwater (akin to ocean-type chinook). It appears that this stock of Fraser River sockeye may be exhibiting behavioural and migration patterns different than expected from the literature, and we propose that this may be reflected in the higher survival rate exhibited by this stock. If this interpretation is correct, then

(BROOD YEAR) OCEAN ENTRY YEAR **(RETURN YEAR)**	(1996) (1998) **2000**	(1997) (1999) **2001**	(1998) (2000) **2002**	(1999) (2001) **2003**	(2000) (2002) **2004**	(2001) (2003) **2005**	(2002) (2004) **2006**	(2003) (2005) **2007**	(2004) (2006) **2008**	(2005) (2007) **2009**
Chilko Marine Survival	G	Y	G	G	R	Y	G	R	Y	NA
Ocean Indices										
1 PDO (Jan-March average)	[illegible]	[illegible]	G	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y	Y
2 ALPI	[illegible]	[illegible]	Y	[illegible]	[illegible]	[illegible]	[illegible]	Y	[illegible]	[illegible]
Physical Conditions										
3 SST (Entrance Island)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	R	[illegible]	Y	Y
4 SST (Pine Island)	[illegible]	[illegible]	[illegible]	[illegible]	Y	[illegible]	[illegible]	[illegible]	Y	G
5 Upwelling index (48°N)	[illegible]	[illegible]	[illegible]	Y	G	[illegible]	Y	[illegible]	Y	G
6 Spring transition timing (48°N)	G	[illegible]	Y	Y	[illegible]	Y	Y	[illegible]	Y	Y
Biological Conditions										
7 Southern Copepods (SVI)	[illegible]	[illegible]	Y	G	[illegible]	[illegible]	Y	R	[illegible]	G
8 Boreal Shelf Copepods (SVI)	[illegible]	[illegible]	[illegible]	Y	G	Y	R	[illegible]	[illegible]	G
9 Southern Copepods (NVI)	[illegible]	[illegible]	[illegible]	[illegible]	Y	[illegible]	Y	[illegible]	[illegible]	G
10 Boreal Shelf Copepods (NVI)	Y	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	R	R	Y	G

Table 2. Indicators of ocean conditions from 1998 to 2007. For each indicator, annual estimates were ranked across all years from 1 to 10 from best to worst salmon ocean survival conditions. Green (G): ranks 1 to 4; yellow (Y): ranks 5 to 7; red (R): ranks 7 to 10.

The presence of many Green boxes in 2009 in Table 2 is an encouraging sign for Fraser River sockeye fishing after several years of low returns.

Salmon Forecasts (Juvenile Data in the Strait of Georgia)

Research fisheries in the Strait of Georgia capture small numbers of juvenile salmon at several times each year, using standard trawl methods and locations. From year-to-year changes in these catches scientists are able to provide insight into future returns of these species. In recent years adult returns are forecasted using CPUE of juvenile salmon in July midwater trawl surveys and use the red/amber/green system. The ability to forecast returns for individual stocks has improved in recent years with the development of DNA methods that can be used to identify the stock of juvenile salmon caught in the marine environment.

Sockeye:

Juvenile sockeye catches are generally quite low in Strait of Georgia and coastal surveys, therefore, no quantitative forecasts based on juvenile abundances in the ocean have been possible. Some preliminary DNA samples have been analyzed for juvenile sockeye collected in July, September and November trawl surveys. In July, catches of juvenile sockeye were generally confined to Howe Sound, with small catches in the northern Strait of Georgia and in the Gulf Islands. By September, catches were primarily along the mainland coast up to Malaspina Strait. By November, no sockeye were found in Howe Sound, but large numbers were still present in the Gulf Islands region. DNA analysis of these fish showed that an overwhelming percentage (97%) of the sockeye in both the Strait of Georgia and in the Gulf Islands were of Harrison River origin. Harrison River sockeye are unusual along the west coast in that they migrate to sea as fry rather than spending a winter in freshwater (akin to ocean-type chinook). It appears that this stock of Fraser River sockeye may be exhibiting behavioural and migration patterns different than expected from the literature, and we propose that this may be reflected in the higher survival rate exhibited by this stock. If this interpretation is correct, then

Harrison River sockeye are behaving more like pink salmon, and the mechanisms that relate to their improved survival are keys to understanding how the Strait of Georgia is changing.

Coho:

Marine survival of Puget Sound coho salmon continues to be superior to that of Strait of Georgia stocks, having recovered to a greater degree from the extremely low levels of both regions in the late 1990s. An examination of midwater trawl data shows a continuous decline in the summer (May-September) survival rate of juvenile coho in the Strait of Georgia. This, in turn, is highly correlated to the total marine survival of coho from 1977-2006 (R2=0.68; Figure 17).

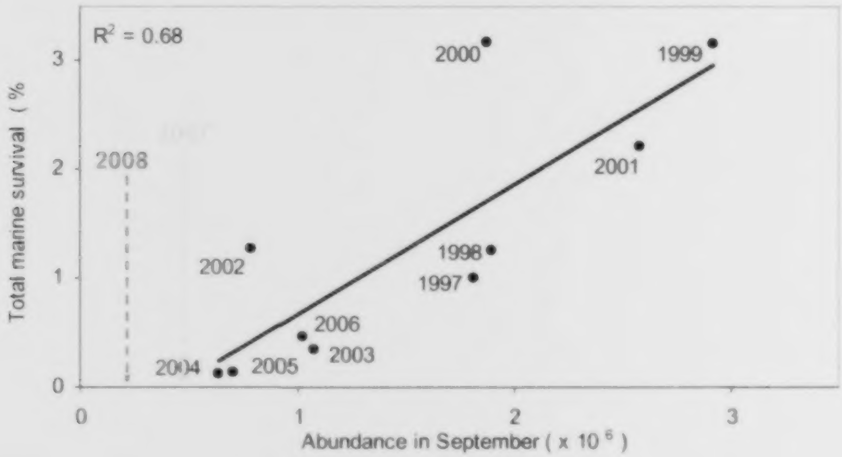


Figure 17. Relationship between September abundance of juvenile coho and marine survival in the Strait of Georgia. Final survival values for 2007 and 2008 not yet available.

One possible explanation for the lower early marine survival in the Strait of Georgia is the higher surface water temperatures, some 1-2°C greater than observed in Puget Sound, which translates into greater thermal stress as the summer proceeds. This temperature difference may be driven by differences in oceanographic conditions between these two regions. For coho salmon, the CPUE in 2008 was the lowest observed since 1997, therefore a very poor return was projected in 2009. In general, observed early marine survival for coho salmon is reduced. Figure 17 also reveals a discouraging crash in the September catch of juvenile Coho in the Strait of Georgia in 2007 and 2008, which implies very low returns in future years if the relationship of abundance to marine survival of Figure 17 holds in the future.

Chinook:

Chinook salmon marine survival, on the other hand, does not show the same degree of disparity between Puget Sound and Strait of Georgia stocks. Although the Puget Sound marine survival rates are generally higher, both long-term and short-term trends are similar. In 2008, a large program was conducted to investigate the survival of Cowichan River Chinook. As part of this program, a large number of DNA samples taken from midwater trawls in both the Gulf Islands and in the Strait of Georgia were analyzed. Interestingly, juvenile Chinook salmon captured in the Gulf Islands in July, September and November show an increasing percentage of Puget Sound Chinook (2%, 6%, and 15%, respectively), demonstrating that this region may be utilized as over-winter rearing grounds by some stocks. A large number of Fraser River stocks of Chinook were also observed, but declining over the summer/fall (62% in June, 43% in September, and 19% in November). This has been interpreted as general movement out to the

WCVI feeding grounds. Cowichan River Chinook and east Vancouver Island stocks (mainly Puntledge) made up the rest of the population structure, increasing in percentage over time and comprising nearly 70% of the juvenile Chinook population by November. Our preliminary interpretation is that some key populations such as the Cowichan Chinook remain in local habitats for the early marine period that determines brood year strength. Thus it is the productivity of these local areas such as the Gulf Islands that are critical to the success of these populations.

Analysis of Chinook captured on the same surveys in the Strait of Georgia presented a much different picture. Puget Sound stocks were generally not found in any great percentage until November, a survey which focussed on the southern portion of the Strait of Georgia. Cowichan River Chinook were also not observed in any great numbers in the Strait of Georgia, confirming Coded Wire Tag data that these fish do not generally utilize these waters. While the July survey showed a wide variety of stocks in the Strait of Georgia, by September the ecosystem was dominated by South Thompson Chinook (79%).

Chinook salmon results are preliminary and indicate very poor total marine survival (about 0.1%). Cowichan Chinook from the hatchery may experience about 95% mortality by September of the first marine year. It is necessary to determine the reasons for the increasing trend of early marine mortality. We suspect that reduced growth results in an increased susceptibility to disease, but this remains speculative.

APPENDIX 1 – AGENDA

PSARC Fisheries and Oceanography Working Group (FOWG) Annual Meeting – IOS

17 to 18 February 2009

	Climate Indices, Meteorology, Gulf of Alaska
William Crawford	Ocean conditions; large-scale climate indices
Howard Freeland	Monitoring the Gulf of Alaska using Argo
Sonia Batten	Zooplankton in the Gulf of Alaska
Jennifer Boldt	Alaska marine ecosystems
Colin Campbell	Ocean indicators and the Sierra Club
Marie Robert	Conditions along Line-P
Roy Hourston	Upwelling winds
	Mostly West Coast
Peter Chandler	Temperatures and salinities
John Holmes	Albacore tuna in BC waters
Ian Perry	Small-mesh multi-species surveys
Jim Gower	Satellite images and weather buoy data
Gary Borstad	Chlorophyll time series and their relationship to marine life
Yuri Zharikov	Seabirds, grey whales and bivalves
Frank Whitney	Impacts of hypoxia along the BC coast
Phillip Edgar	Nitinat Lake
Ron Tanasichuk	Euphausiids and fish production
Jake Schweigert	Herring and sardines
Alan Sinclair	Groundfish distributions in relation to oceanographic conditions
Chuck Parken	Trends in Chinook abundance
Marc Trudel	Juvenile salmon
Kim Hyatt	Sockeye marine survival trends
Hussein Alidina	PNCIMA ecosystem and CPAWS/WWF
	General discussion
	Mostly Georgia Basin
Dave Mackas	Zooplankton along Vancouver Island
John Morrison	River flows
Richard Dewey	VENUS
Susan Allen	Spring bloom in the Strait of Georgia
Angelica Peña	Phytoplankton in the Strait of Georgia
James Irvine	Coho marine survival patterns and predictions
Caihong Fu	Fish communities & impacts of fishing & climate change
Dick Beamish	Juvenile salmon in the Strait of Georgia
Sue Grant	Forecasts & ocean indicators for sockeye
Skip McKinnell	Ocean/climate forecasts & Fraser (Chilko} sockeye
	General discussion
	Discussion: synthesis, anomalies, key points
	Discuss report format and deadline for submission.

APPENDIX 2 – CONTRIBUTORS TO THIS REPORT

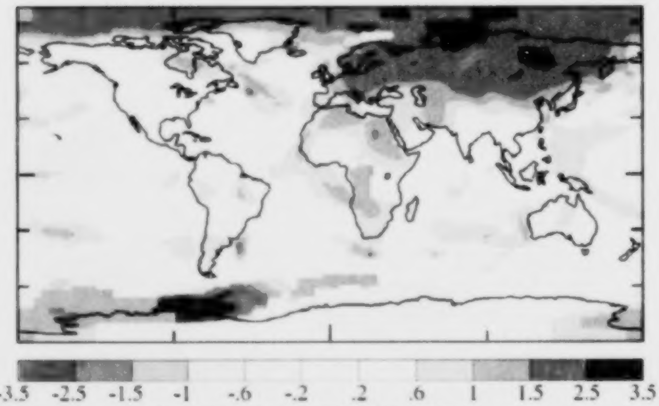
Susan Allen	UBC	Steven Baillie	DFO	Sonia Batten	SAHFOS
Richard Beamish	DFO	David Blackbourn	Contr.	Jennifer Boldt	JISAO
Gary Borstad	Bstad	Gayle Brown	DFO	Leslie Brown	Bstad
Jim Boutillier	DFO	Peter Chandler	DFO	Peter Clarkson	P-Can
Bill Crawford, Edit.	DFO	Richard Dewey	VENUS	Deborah Faust	DFO
Howard Freeland	DFO	Moira Galbraith	DFO	Jim Gower	DFO
Sue Grant	DFO	Bob Hansen	P-Can	Heather Holmes	P-Can
John Holmes	DFO	Jim Irvine, Editor	DFO	Roy Hourston	Contr.
Kim Hyatt	DFO	Natashya Klus	DFO	Doug Latornell	UBC
Krista Lange	DFO	David Mackas	DFO	Skip McKinnell	PICES
Rick McNicol	DFO	John Morrison	Vynx.	Chrys Neville	DFO
David O'Brien	DFO	Chuck Parken	DFO	Angelica Peña	DFO
Ian Perry	DFO	David Preikshot	DFO	Paul Rankin	DFO
Marie Robert	DFO	Dennis Rutherford	DFO	Jake Schweigert	DFO
Alan Sinclair	DFO	Margot Stockwell	DFO	Ruston Sweeting	DFO
Ron Tanasichuk	DFO	Tom Therriault	DFO	Richard Thomson	DFO
Marc Trudel	DFO	Frank Whitney	DFO	Peter Willis	Bstad
Megan Wolfe	UBC	Yuri Zharikov	P-Can		

Bstad	ASL Borstad Remote Sensing Inc., North Saanich, BC
Contr.	Private Contractor
DFO	Fisheries and Oceans Canada, Pacific Region
JISAO	Joint Institute for the Study of the Atmosphere and Ocean, U. of Washington
P-Can	Pacific Rim National Park Reserve of Canada, Ecosystem Secretariat
PICES	North Pacific Marine Sciences Organization
SAHFOS	Sir Alister Hardy Foundation for Ocean Science, UK
UBC	University of British Columbia, Dept of Earth and Ocean Sciences, Vancouver
VENU	Victoria Experimental Network Under the Sea, University of Victoria, Victoria
Vynx	VYNX Design Inc, Victoria, BC

APPENDIX 3 – INDIVIDUAL REPORTS

GLOBAL CONDITIONS IN 2008

Bill Crawford, Fisheries & Oceans Canada



Source: http://data.giss.nasa.gov/gistemp/2008/

Figure 1. Annual surface temperature anomaly for 2008 (°C). relative to 1961 to 1991. Image provided by Goddard Institute for Space Studies

Global surface temperature in 2008 was more than a degree warmer than normal over much of the Northern Hemisphere. However, ocean anomalies were minus 0.6 to minus 1.0°C off the west coast of Canada, one of the few regions to experience such relatively cool temperatures Figure 2 below reveals the global warming since 1880. Although temperatures in 2008 were clearly warmer than the average over this period, the rapid global warming from late 1970s to the beginning of this century has reached a plateau. La Niña conditions over the past few years are a likely factor in this plateau of temperature. La Niña years are generally cooler than others, while El Niña years are warmer. Note that the land has warmed more rapidly than the ocean since 1970.

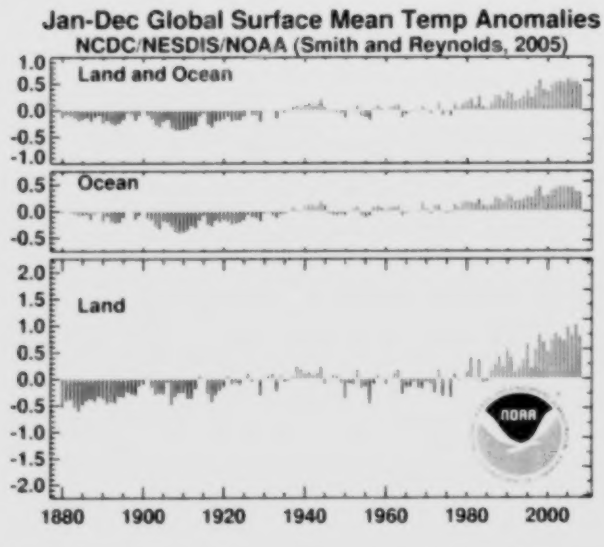


Figure 2. Annual anomalies of surface temperature (°C) since 1880, referen-ced to 1961 to 1991.

GULF OF ALASKA

Very cool ocean in Gulf of Alaska

Bill Crawford, Fisheries & Oceans Canada

La Niña developed in the equatorial Pacific Ocean during the Northern Hemisphere winter of 2007-2008. It reached a peak in January 2008 when the Niño 3.4 region along the Equator was at its coldest temperature, as shown in the top panel of Figure 1 below. Generally, stronger trade winds in the tropical Pacific Ocean lead to La Niña and cooler waters of the Niño 3.4 region. Through atmospheric teleconnections, La Niña events typically bring stronger westerly winds to our latitudes and to cooler waters along the west coast of Canada. Although La Niña abated during the summer of 2008 (see middle panel of Fig. 1), La Niña-like trade winds returned later in 2008 as revealed by relatively cold temperatures on the Equator in Dec. 2008., and cool anomalies continued along the Canadian west coast well into the spring of 2009.

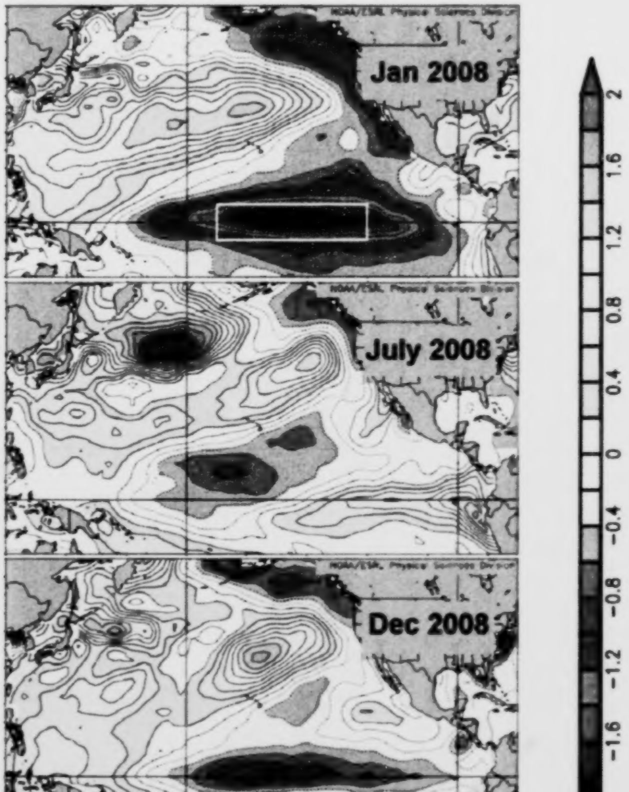


Figure 1. Sea surface temperature anomalies for three months in 2008: January (top), July (middle), and December (bottom). Scale at right is in °C. The white-bordered box in top panel outlines the Niño 3.4 region whose temperature determines El Niño and La Niña Indices.

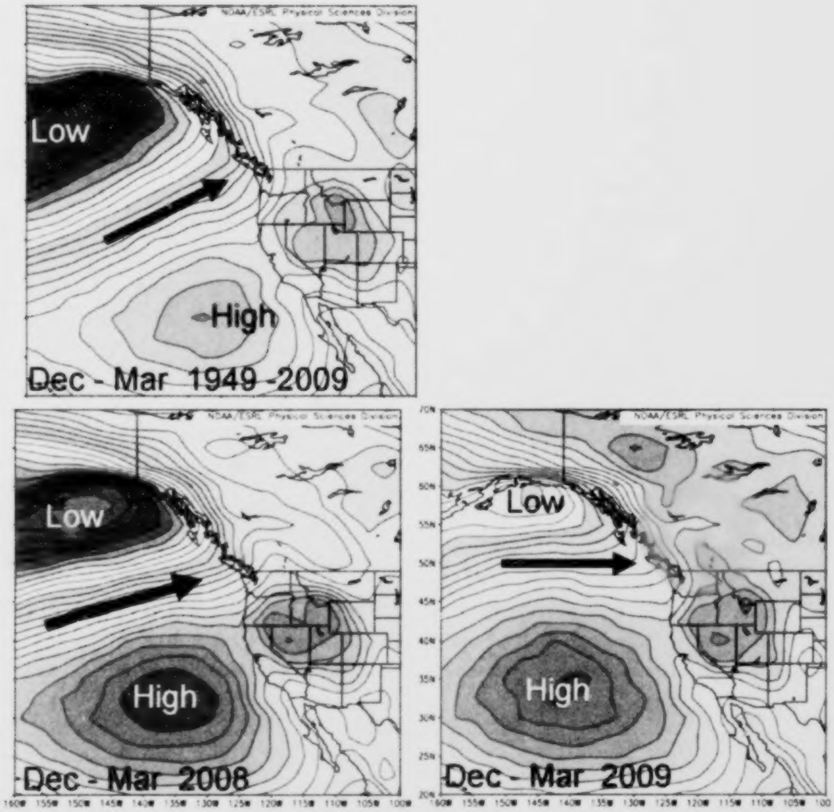


Figure 2. Contours of sea-surface air pressure for the Gulf of Alaska and western North America, averaged over December to March. The month of March determines the year in the label in each panel. Pressure contours are in millibars, with the same scale in each panel, and a contour interval of 1 mbar. Labels "High" and "Low" denote centres of the North Pacific High and Aleutian Low, respectively. Black arrows are aligned with pressure contours to denote the winter-averaged winds that correspond to these pressure distributions.
Above: Average winters from 1949 to 2009. Below: Winter 2008 (left) and 2009 (right).

The winter-long distribution of air pressure tells us what temperature anomalies we can expect over the eastern Gulf of Alaska and over the west coast of Canada. In normal winters the Aleutian Low is centred over the northwest Gulf of Alaska and a weak North Pacific high develops west of California and Mexico (Fig. 2, top panel). Surface winds of a normal winter blow from the southwest, bringing warm air and waters to our coast. In the past two winters the North Pacific High strengthened and moved westward, while the Aleutian Low either remained in place or moved eastward. As a result, winds of the past two winters were more from the west, bringing cooler air and ocean currents toward the Canadian coast. In the 2008 winter both the Aleutian Low and north Pacific High were stronger than normal, greatly increasing the strength of the winter-average wind, as indicated by more closely spaced isobars and a longer wind vector in the bottom left panel of Fig. 2.

GULF OF ALASKA

Very cool ocean in Gulf of Alaska

Bill Crawford, Fisheries & Oceans Canada

La Niña developed in the equatorial Pacific Ocean during the Northern Hemisphere winter of 2007-2008. It reached a peak in January 2008 when the Niño 3.4 region along the Equator was at its coldest temperature, as shown in the top panel of Figure 1 below. Generally, stronger trade winds in the tropical Pacific Ocean lead to La Niña and cooler waters of the Niño 3.4 region. Through atmospheric teleconnections, La Niña events typically bring stronger westerly winds to our latitudes and to cooler waters along the west coast of Canada. Although La Niña abated during the summer of 2008 (see middle panel of Fig. 1), La Niña-like trade winds returned later in 2008 as revealed by relatively cold temperatures on the Equator in Dec. 2008., and cool anomalies continued along the Canadian west coast well into the spring of 2009.

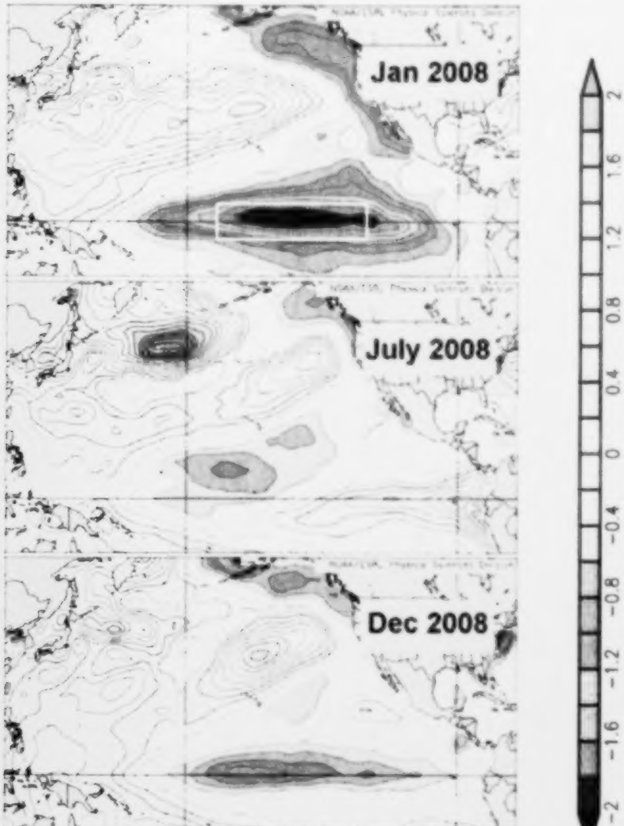


Figure 1. Sea surface temperature anomalies for three months in 2008: January (top), July (middle), and December (bottom). Scale at right is in °C. The white-bordered box in top panel outlines the Niño 3.4 region whose temperature determines El Niño and La Niña Indices.

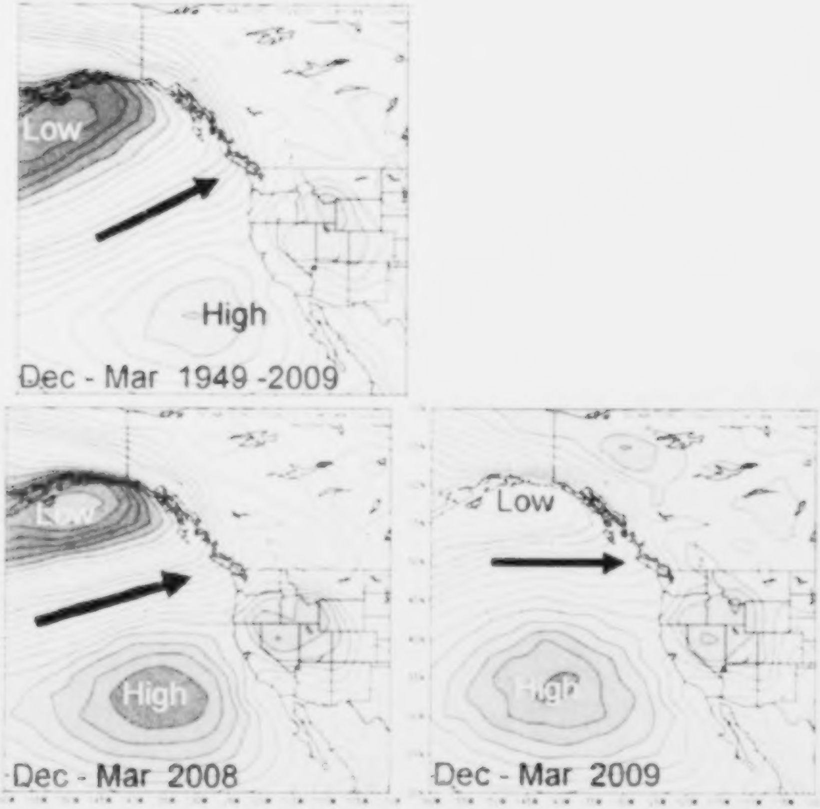


Figure 2. Contours of sea-surface air pressure for the Gulf of Alaska and western North America, averaged over December to March. The month of March determines the year in the label in each panel. Pressure contours are in millibars, with the same scale in each panel, and a contour interval of 1 mbar. Labels 'High' and 'Low' denote centres of the North Pacific High and Aleutian Low, respectively. Black arrows are aligned with pressure contours to denote the winter-averaged winds that correspond to these pressure distributions.
Above: Average winters from 1949 to 2009. Below: Winter 2008 (left) and 2009 (right).

The winter-long distribution of air pressure tells us what temperature anomalies we can expect over the eastern Gulf of Alaska and over the west coast of Canada. In normal winters the Aleutian Low is centred over the northwest Gulf of Alaska and a weak North Pacific high develops west of California and Mexico (Fig. 2, top panel). Surface winds of a normal winter blow from the southwest, bringing warm air and waters to our coast. In the past two winters the North Pacific High strengthened and moved westward, while the Aleutian Low either remained in place or moved eastward. As a result, winds of the past two winters were more from the west, bringing cooler air and ocean currents toward the Canadian coast. In the 2008 winter both the Aleutian Low and north Pacific High were stronger than normal, greatly increasing the strength of the winter-average wind, as indicated by more closely spaced isobars and a longer wind vector in the bottom left panel of Fig. 2.

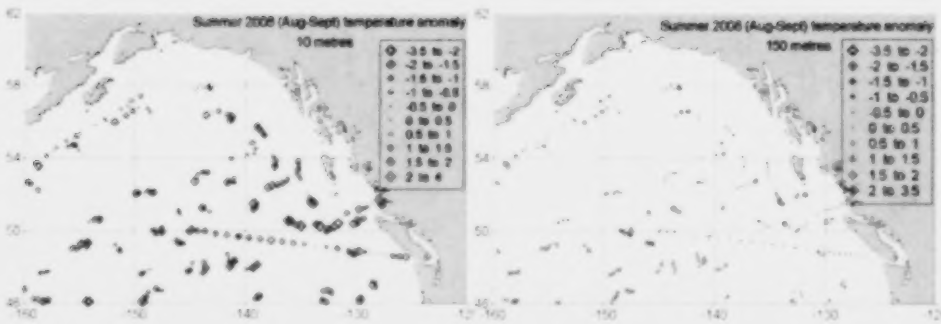


Figure 3. Anomalies of ocean temperature (°C) in summer 2008 at 10-metres depth (left panel) and 150-metres depth (right), referenced to average summers of 1929 to 2005. Each symbol represents a measurement of temperature by autonomous Argo profilers and by scientists on research ships. The colour of each symbol denotes whether positive anomaly (red) or negative (blue). Size of each symbol denotes magnitude of the anomaly according to the scale along the right side of each panel.

The maps in Figure 3 reveal locations of measurements of temperature taken by Argo floats and by the DFO Line P Program. The symbols reveal basin-wide cooling of the Gulf of Alaska surface waters. This cooling reached several degrees at most locations in the summer of 2008.

Temperatures at 10-metres depth (rather than at ocean surface) are plotted because sensors of both Argo and ship-based devices perform better at this depth. Temperature at 10 metres is a good indicator of surface temperature.)

At 150-metres depth the waters over the northern gulf were somewhat cooler than normal (see Fig. 3, right panel), whereas south of 49°N the temperatures were warmer than normal. Temperature at this depth is normally determined by winds of the previous winter, and cool water in the north at 150 metres might be due to a more easterly location of the Aleutian Low in the 2008-2009 winter.

Figure 4. Anomalies of ocean salinity in summer 2008 at 10 metres depth (left panel) and 150 m depth (right), referenced to average summers of 1929 to 2005. Each symbol represents a single measurements of salinity by Argo profilers and by scientists on research ships. The colour of each symbol denotes whether positive anomaly (red) or negative (blue). Size of each symbol denotes magnitude of the anomaly according to the scale in each panel.

Salinity measurements at 10 metres depth, in Figure 4, reveal only a weak pattern in summer of 2008. Mid-gulf anomalies were negative, whereas anomalies close to the Canadian coast were positive. Positive salinity anomalies at 150 metres depth in the northern gulf (together with negative temperature anomalies shown in Figure 3) suggest stronger upwelling occurred in the previous winter in this part of the Gulf of Alaska (Dec 2007 to Mar. 2008).

Figure 2 shows that the centre of the Aleutian Low in this winter was stronger than normal and located directly over the northern Gulf of Alaska. As a result, much stronger cyclonic winds blew over this region, leading to stronger upwelling under this low pressure system.

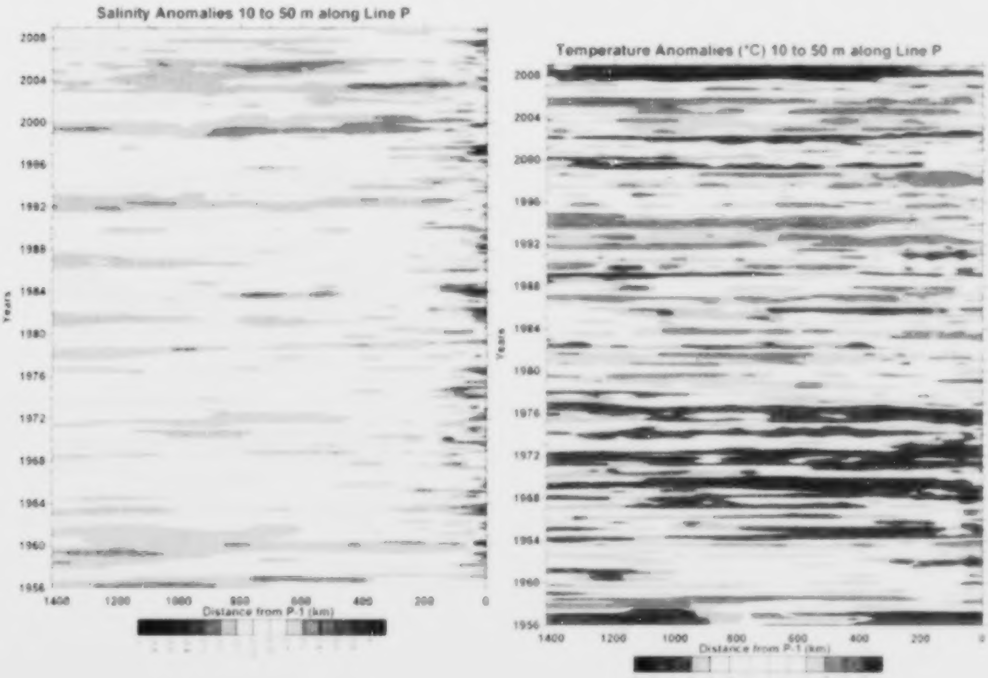


Figure 5. Time-distance plot of anomalies of temperature (°C left) and salinity (right) along Line P, which is a set of ocean stations extending from the western entrance of Juan de Fuca Strait to Ocean Station Papa at 50°N, 145°W in the Gulf of Alaska. Scale bars are below each panel. The horizontal axis denotes distance west from Station P1 on the continental shelf of Vancouver Island near Juan de Fuca Strait. Vertical axes present the year of the anomalies. Details of how this plot was prepared are presented by Crawford, Galbraith and Bolingbroke, 2007, Progress in Oceanography Vol. 75, p 161-178).

The strong cooling in 2008 in the Gulf of Alaska has been noted previously. The graph in Figure 5 shows this cooling compared to the previous 52 years. Each panel of Fig. 5 presents contours of anomalies over the depth range of 10 to 50 metres below surface, based on all measurements in data archives at the US National Ocean Data Center in Washington DC, the Canadian Marine Environmental Data Service in Ottawa, and at the Institute of Ocean Sciences in Sidney BC.

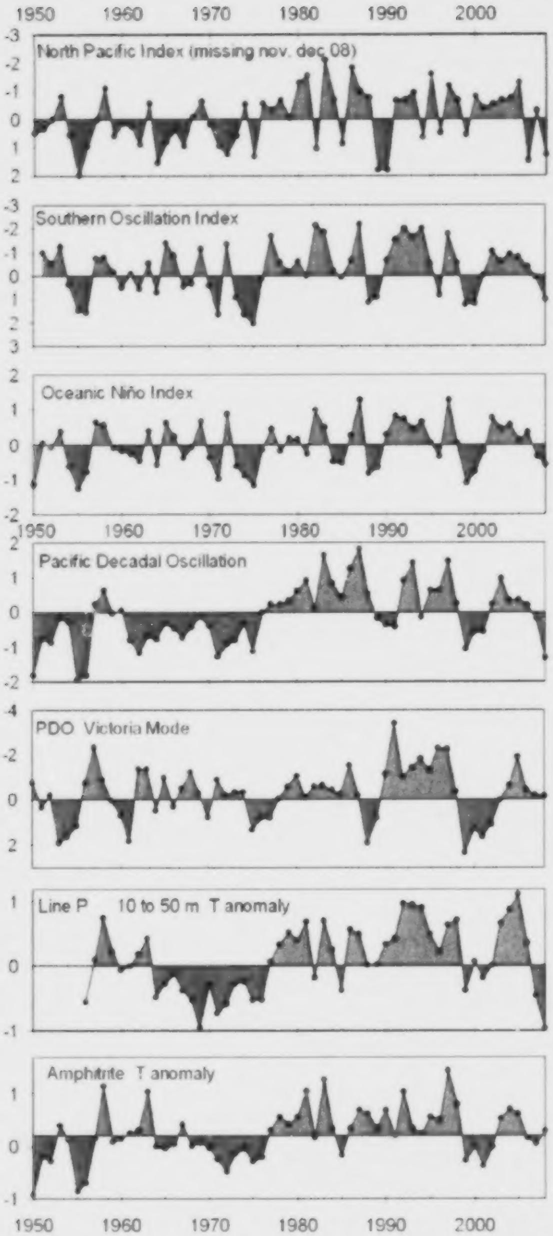


Figure 6. Pacific Ocean climate Indices and temperature anomalies (°C). The North Pacific Index, the Southern Oscillation Index and the PDo–Victoria Mode are inverted so their variability is in phase with other series. Figure 6 displays a 58-year time series representing climate of the North Pacific Ocean as well as the Southern Oscillation Index and the Oceanic Niño Index.

Blue regions denote negative anomalies and relatively cool waters (left panel) and relatively fresh waters (right panel). The cooling of late 2007 and all of 2008 was greater than found along

Line P since the mid 1970s. Interestingly, in 2005, only three years earlier, these same waters were the warmest of this instrument record. This sudden decrease in temperature in 2005 to 2008 is greater than any previous measured drop at Line P.

Salinity anomalies were not nearly as extreme as the temperature anomalies, although the relatively fresh conditions since 2001 continue to persist along Line P.

Most of these series display common variability, with blue regions prevailing prior to the regime shift near 1977, and red regions after then. Most time series shift from red to blue for several years centred on 2000 and again in 2007-2008. (Note the shift from warm to cold along Line P from 2005 to 2008.) These shifts indicate cooling in the eastern Gulf of Alaska (Line P) and along the west coast of Vancouver Island (Amphitrite Point), and in Niño 3.4 (Oceanic Niño Index). In general, cooling aligns with La Niña, negative PDO and Aleutian Low Pressure Index, positive Victoria Mode, and the Southern Oscillation Index.

Warming along Line P and at Amphitrite Point in mid-2000s coincided with El Niño, positive PDO and negative PDO- Victoria Mode. Cooling in the past three years accompanies La Niña and negative PDO, and usually positive PDO-Victoria mode. Although the PDO-Victoria Mode was "blue" for much of 2008, it shifted in summer 2008 and its overall annual average was close to zero.

Sources of data for time series plotted in Fig. 6 at left are listed below.

North Pacific Index (NPI) is the area-weighted sea-level pressure over the region 30°N to 65°N and 160°E to 140°W. Monthly time series of this index are provided by the Climate Analysis Section, NCAR, Boulder, USA, http://www.cgd.ucar.edu/cas/jhurrell/npindex.html based on Trenberth and Hurrell (1994). This index is a useful indicator of the intensity of the Aleutian Low Pressure system. Both monthly and winter-only values are available.

Trenberth, K. and J. Hurrell, 1994: Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics, 9, DOI; 10.1007/BF00204745, 303-319.

Southern Oscillation Index is available at: http://www.cpc.ncep.noaa.gov/data/indices/soi. It represents the atmospheric pressure gradient along the Equator in the Pacific Ocean that usually sets up the El Niño and La Niña ocean responses.

Oceanic Niño Index (ONI) is the anomaly of temperature in degrees Celsius in the Nino 3.4 region on the Pacific Equator. Time series of this index are provided by the NOAA/ National Weather Service, National Center for Environmental Prediction, Climate Prediction Center, Camp Springs, Maryland, USA.

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Pacific Decadal Oscillation (PDO) is based on analysis of Mantua et al. (1997) and Zhang et al. (1997). The time series was provided at an Internet site of the Joint Institute for Studies of Atmosphere and Ocean of NOAA in Seattle: http://jisao.washington.edu/pdo/PDO.latest

Mantua, N.J. and S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis,1997: A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society, 78, pp. 1069-1079.

Zhang, Y., J.M. Wallace and D.S. Battisti, 1997: ENSO-like interdecadal variability: 1900-93. Journal of Climate, 10, 1004-1020.

PDO – Victoria Mode is first described by Bond et al. (2003). The time series was provided by Muyin Wang of JISAO/NOAA, in Seattle. For this analysis she computed the EOF patterns based on 1950-99 SST and then regressed the SST to the spatial patterns to get the entire time

series. The advantage of doing this is that from now on, the old numbers won't change, and each year one can simply add one more new number at the end. The SST data used is the HadCRUT3v.

Bond, N. A., Overland, J.E., Spillane, M., Stabeno, P., 2003: Recent shifts in the state of the North Pacific. Geophysical Research Letters, 30(23), 2083, doi:10.1029/2003GL018597.

Line P temperature anomalies are based on Crawford et al. (2007) and are available at the Internet site: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/linep/linepselectdata_e.htm.

Crawford, W., J. Galbraith, and N. Bolingbroke, 2007: Line P ocean temperature and salinity, 1956-2005. Progress in Oceanography, 75, 161-178, doi:10.1016/j.pocean.2007.08.017.

Monthly average Amphitrite temperature anomaly time series are based ocean surface temperatures measured daily at the Amphitrite Lighthouse, one of 11 stations along the coast that are part of the Lighthouse monitoring Program funded by Fisheries and Oceans Canada. Monthly temperature time series are provided by Fisheries and Oceans Canada at this Internet site: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm

Northeast Pacific Sea Level Index

Patrick Cummins, Fisheries & Oceans Canada

Sea level anomalies measured by satellite altimetry may be used to construct an index of variability over the northeast Pacific Ocean (Cummins et al., 2005). On interannual time scales these anomalies reflect changes in sea level associated mainly with integrated temperature anomalies through the top few hundred meters of the water column. The sea level index is a time series calculated by regressing observed sea level anomalies onto the leading empirical orthogonal function (EOF) over the region. The EOF amplitude time series is computed by fitting the data set to the 15-year base period eigenvectors (1993-2007). The EOF1 amplitude is then normalized by its standard deviation. As such, it is indicative of large-scale, low frequency variability. The EOF pattern is presented in Fig. 1 and consists of a negatively-signed region centered at 35°N, 195°E, surrounded by a broad region of opposite sign extending along the eastern and northern margins of the basin.

Figure 2 presents the northeast Pacific sea level index for the 16 year period, 1993-2008. For comparison, the figure also includes the recent history of the Pacific Decadal Oscillation (PDO Mantua et al., 1997), which is based on sea surface temperature. The two indices are complementary and show generally similar variations. However, the sea level index displays considerable less short-period variability than the PDO, arguably providing a better indication of long period, upper ocean variability.

Following the 1997/98 El Niño, a strong La Niña episode occurred in the tropical Pacific in 1999. Fig. 2 shows that this event was associated with a marked shift to negative values of the sea level index, and also to the negative phase of the PDO. This state persisted for about 4 years to the end of 2002. During this time, sea level and sea surface temperatures were generally below average on the eastern side of the North Pacific and in the Gulf of Alaska. During the subsequent three years (2003-2005) the PDO returned to its warm phase while the sea level index showed near-neutral to weakly positive values.

Since the end of 2005, the sea level index has descended, reaching significant negative values in 2007-2008. This period is characterized by persistent, negative sea level anomalies in the Gulf of Alaska and eastern North Pacific in a broad horseshoe-shaped pattern (Crawford and Cummins, 2007). From mid-2005 through mid – 2007, the PDO varied without a consistent trend. However starting in the second half of 2007, and in response to the development of a moderate-to-strong La Niña episode, the PDO turned to decidedly negative values. This is associated with below-average SSTs around the eastern margin of the basin. Based on the state of the sea level index and the PDO at the end of 2008, the outlook for 2009 is for continued lower sea level and below-average upper ocean temperatures over the northeast Pacific and the Gulf of Alaska.

References:

Crawford, W. and P. Cummins (2007) Recent trends in the subarctic NE Pacific: Cooling of 2006 continues into 2007. Pices Press, Vol. 15, No. 2, p. 26-27.

Cummins, P.F., G.S.E. Lagerloef and G. Mitchum (2005) A regional index of northeast Pacific variability based on satellite altimeter data. Geophysical Research Letters, 32: L17607 doi:10.1029/2005GL023642.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis, 1997. A Pacific decadal climate oscillation with impacts on salmon. Bulletin of the American Meteorological Society, 78, 1069-1079.

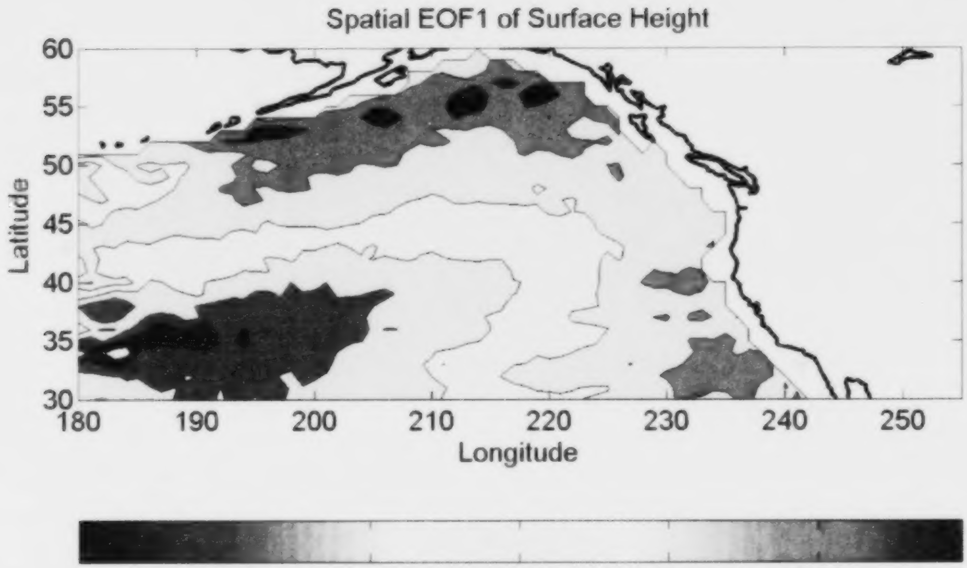


Figure 1. Spatial pattern of the leading EOF of sea level anomalies over the NE Pacific. From the Earth and Space Research web page: http://www.esr.org/pdo_index.html

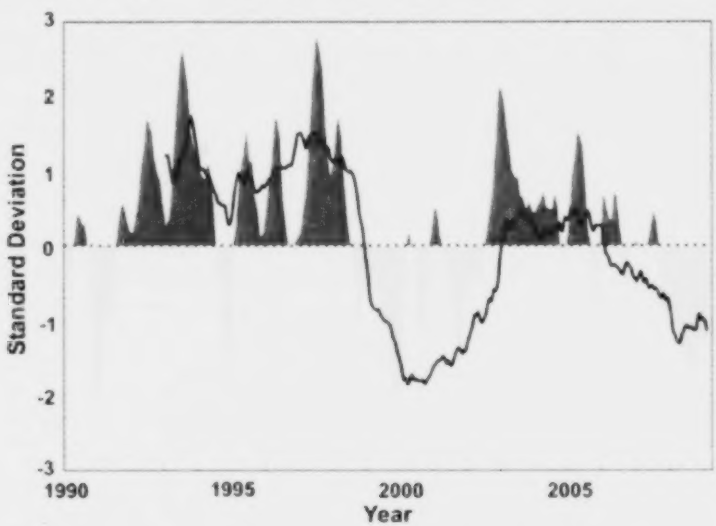


Figure 2. The solid black curve gives the northeast Pacific sea level index with positive (negative) values indicating above (below) average sea level over the Gulf of Alaska and the northeast Pacific Ocean region shown in Figure 1. The PDO index is shown in solid colours with blue (red) indicating the PDO cold (warm) phase. Both indices have been normalized by their standard deviations and smoothed with a 3-month running-mean filter.

Argo views the Gulf of Alaska

Howard Freeland, Fisheries & Oceans Canada

Argo has had a global array of more than 3000 autonomous floats in place now more than a year and has been able to map properties in the Gulf of Alaska for a much longer time. Most properties of the ocean are mapped using "objective analysis". One of the valuable byproducts of the Gauss-Markov theorem that underpins objective analysis is that it naturally supplies an error estimate that is independent of the property being estimated, this is shown in Figure 1. Where the error estimate is low, confidence is high.

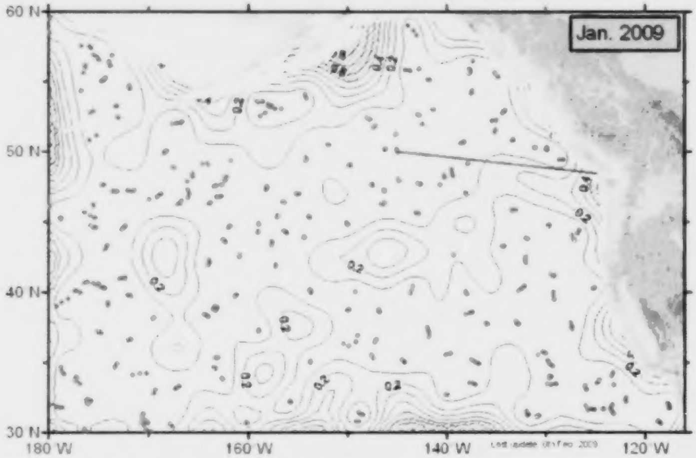


Figure 1: Distribution of Argo float observations during January 2009 (red dots) and the expected error distribution assuming an objective analysis procedure using a Gaussian covariance function. Where expected error is low, confidence is high. Units are standard deviations. For example, on the 0.2 contour we can map mixed-layer depth to within +0.2 standard deviations. The blue line marks Line P. Ocean Station Papa is at its western end.

It is straightforward to interpolate Argo observations onto a site, such as Ocean Station Papa, and create a long time series showing year-by-year variability at that site. Last year I showed a plot of density versus depth and time at Station Papa and noted the large variations in the vertical separation of density surfaces in a time-series. In early 2008 the separation between sigma-t surfaces in the main pycnocline was extremely small, as shown in Figure 2. This separation became more normal in early 2009.

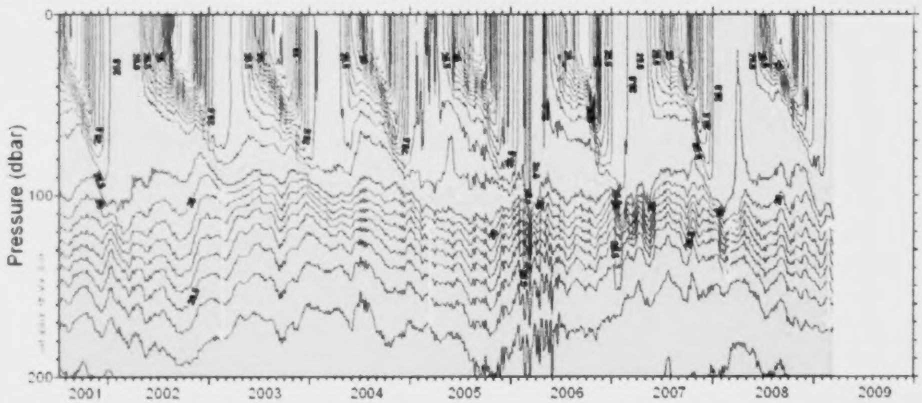


Figure 2. Sigma-t (density minus 1000 kg/m3) versus pressure and time at Ocean Station Papa, based on interpolations from Argo observations.

Argo views the Gulf of Alaska

Howard Freeland, Fisheries & Oceans Canada

Argo has had a global array of more than 3000 autonomous floats in place now more than a year and has been able to map properties in the Gulf of Alaska for a much longer time. Most properties of the ocean are mapped using "objective analysis". One of the valuable byproducts of the Gauss-Markov theorem that underpins objective analysis is that it naturally supplies an error estimate that is independent of the property being estimated, this is shown in Figure 1. Where the error estimate is low, confidence is high.

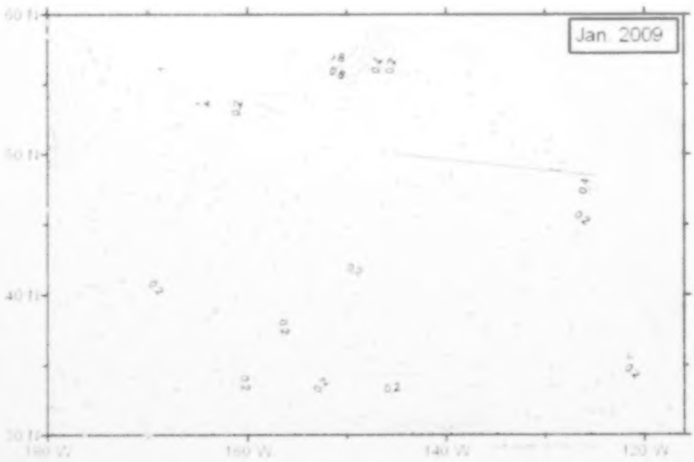


Figure 1: Distribution of Argo float observations during January 2009 (red dots) and the expected error distribution assuming an objective analysis procedure using a Gaussian covariance function. Where expected error is low, confidence is high. Units are standard deviations. For example, on the 0.2 contour we can map mixed-layer depth to within +0.2 standard deviations. The blue line marks Line P. Ocean Station Papa is at its western end.

It is straightforward to interpolate Argo observations onto a site, such as Ocean Station Papa, and create a long time series showing year-by-year variability at that site. Last year I showed a plot of density versus depth and time at Station Papa and noted the large variations in the vertical separation of density surfaces in a time-series. In early 2008 the separation between sigma-t surfaces in the main pycnocline was extremely small, as shown in Figure 2. This separation became more normal in early 2009.

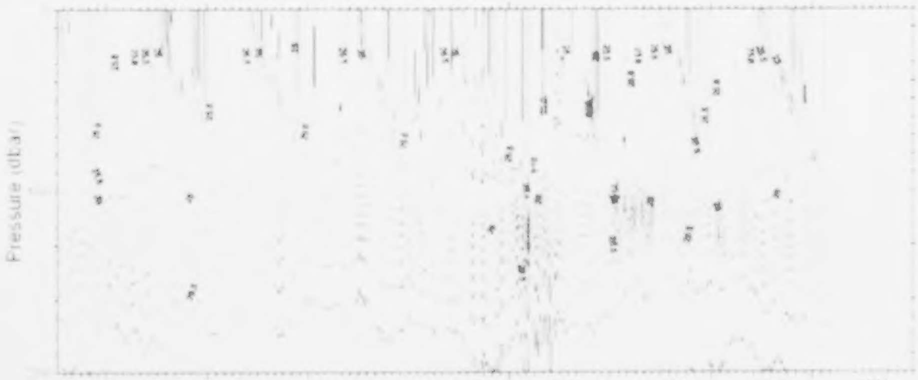


Figure 2. Sigma-t (density minus 1000 kg/m3) versus pressure and time at Ocean Station Papa, based on interpolations from Argo observations.

In Figure 2 the time series of density versus depth and time is shown for the upper 200 metres at Ocean Station Papa. The white arrows show the separation between the density surfaces σt = 26.0 to 26.7. In February of 2003, 2005, 2008 and 2009 this separation was 85m, 60m, 35m and 60m respectively. The green line highlights the 25.8 σt surface and the red line the 25.9 σt surface. A simple computation of the energy required to accomplish mixing down to a specific depth for different water column models shows that as long as we do not drive winter mixing through the main pycnocline, it is easier to mix to moderately deep levels when the density gradient is concentrated, as in winter 2007/08. As the density surfaces spread apart, then more energy is required to mix down to a dense surface such as σt = 25.9. This explains why mixing was unusually deep in the early months of 2008. With the return of the pycnocline structure to normal we must expect less mixing of deep densities and so less supply of deep water to the photic zone in early 2009. The 2009 winter mixing period is not yet over at the time of writing, but it appears tentatively as though this prediction will be borne out as shown in Figure 3.

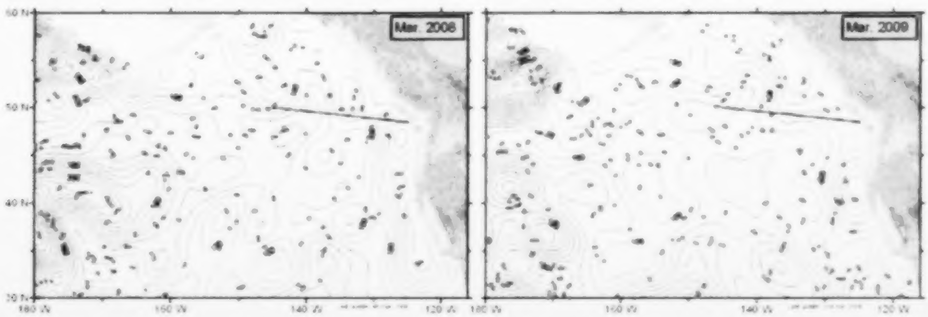


Figure 3. Maps of the mixed layer depth over the whole NE Pacific indicate that mixed layers penetrated less deeply over most of the NE Pacific in March 2009, compared with the previous year. The shaded areas indicate mixed layer depths greater than 120 metres. The blue line marks the location of Line P.

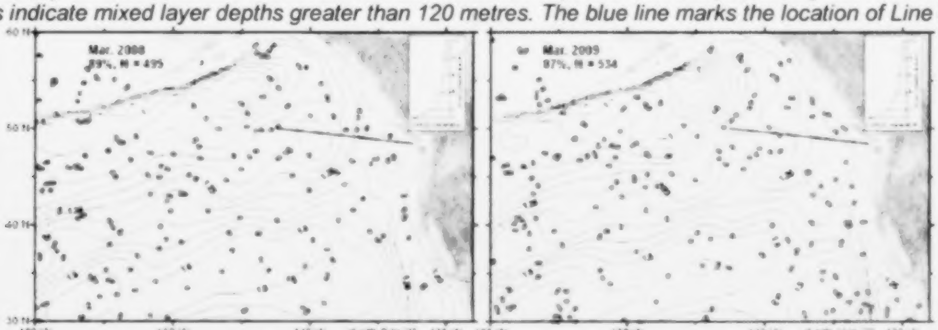


Figure 4. The general circulation of the northeast Pacific in March 2008 and March 2009. The lines are contours of geopotential height, an oceanographic analogue of isobars on weather maps. Ocean currents generally flow along these contours, with higher height to their right. Closer isobars indicate faster currents. These isobars show the North Pacific Current flowing west to east and the split into the northbound Alaska Current and the southbound California Current. The dashed lines indicate the dividing lines; currents north of the dashed line eventually head north and currents south of the dashed line eventually head south. The blue lines marks the location of Line P.

For several years I have been monitoring the strength of the major surface currents in the northeast Pacific Ocean. The history of the northeast Pacific circulation can be viewed at the URL: http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/argo/Dhgts_e.htm . Figure 4 shows maps of the general circulation field for March 2008 and 2009, to match the mixed layer depth maps

above. These show both the general similarity of the overall pattern as well as giving some idea of how much variability is present in the general circulation fields.

Taking the difference in dynamic height between a permanent high sea level location in the sub tropical Pacific and a permanent low in the Alaska Gyre of the Gulf of Alaska (roughly along 150°W) we can monitor the total volume of flow travelling towards the east in the North Pacific Current. This is shown by the black line (and monthly dots) in Figure 5. Part of that water flows into the Alaska Current (shown by the blue line) and part heads southward into the California Current (shown by the green line).

The fraction of North Pacific water that heads into the Gulf of Alaska (the ratio of the blue line divided by the black line) is shown in red and indicates that a lower fraction of North Pacific Current has entered the Alaska Current since Sept. 2007 compared to previous years.

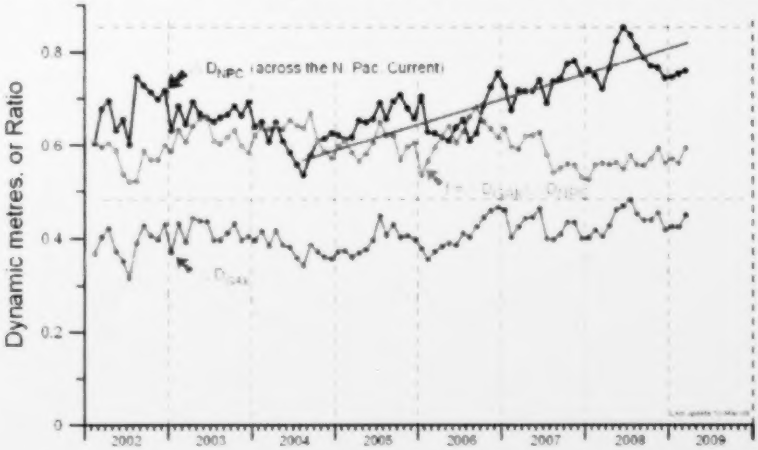


Figure 5: Indicators of the amount of water flowing in each of the major currents in the NE Pacific as determined from measurements by Argo profilers, 2002 to the present time.

What is striking in Figure 5 is the steady and progressive increase in flow of the North PacificCurrent from 2004 to early 2009. The strong transport in mid-2008 was really quite startling. Since then the transport has decreased but still remains very high compared with the 7-year average as seen by Argo floats. The dark purple line indicates a rough linear trend line for North Pacific Current since 2004.

This increase is likely due to stronger westerly winds of winter in these years, as well as a deeper Aleutian Low in winter 2007-08. Simulations of the NE Pacific wind-driven currents have been carried out by Di Lorenzo (2008, Geophys. Research Letters, 35, L08607, doi:10.1029/2007GL032838) and these also show the steady increase of the North Pacific Current from 2004 to the present time. It is likely important for the ecosystems of the Gulf of Alaska that in 2008 the transport into the Gulf of Alaska from the west was the largest we have ever seen since we first were able to monitor these transports and their variability in 2002, and may have contributed to higher nutrient levels in the spring of 2008 and increased mass of plankton observed in the gulf in the summer of 2008, described in later articles in this report.

Conditions along Line P in 2008 and early 2009

Marie Robert and Frank Whitney, Fisheries & Oceans Canada

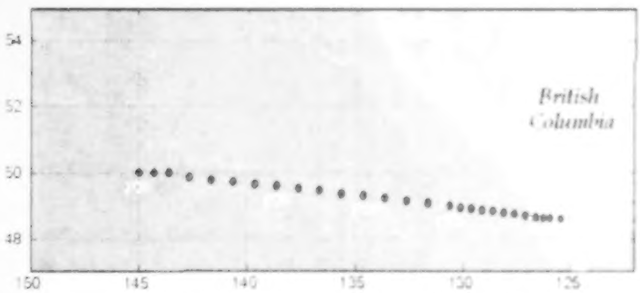


Figure 1. Line P and Ocean Station Papa (P26)

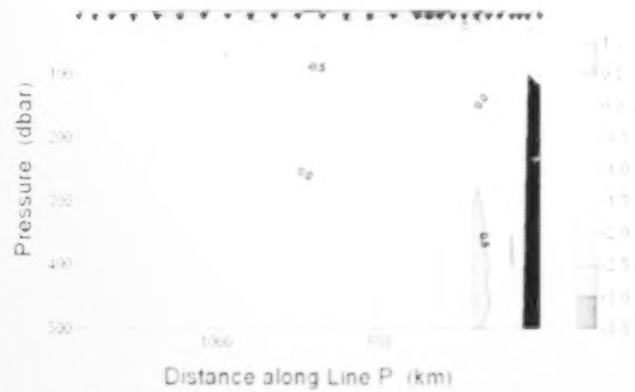


Figure 2. Temperature anomaly field along Line P in June 2008 compared to the 1956-1991 average

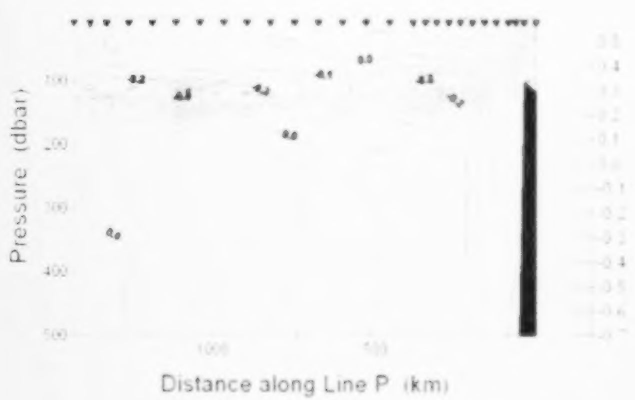


Figure 3. Salinity anomaly field along Line P in Aug. 2008 compared to the 1956-1991 average

Line P is a series of ocean stations extending from the mouth of the Juan de Fuca Strait south of Vancouver Island to Ocean Station Papa at 50°N 145°W. (Fig. 1). The Line P time series is one of the longest deep-sea time series in the world, with data back to 1956. Research vessels of Fisheries & Oceans Canada visit Line P three times per year, usually in February, June, and August.

2008 was a cold year along Line P, both with respect to the long-term average (1956 – 1991) as well as with respect to recent years (2001 – 2007). The temperature anomaly at the surface reached -3.2°C in June 2008 compared to the long-term average (Fig. 2), and almost -4°C compared to the temperatures of the most recent warm year, 2005. This cold anomaly was evident during each cruise in 2008 (Feb., Jun. and Aug.)

The waters along Line P in 2008 were generally fresher than the long-term average except for the inshore surface waters, which were much saltier (Figure 3). The salinity anomaly between 100 and 125 metres depth shows a freshening of the top of the halocline, an indication of deeper wind-forced mixing which probably occurred in late winter. This anomaly is seen both in June and August 2008, and likely explains higher nutrient levels in the mixed layer in winter.

Conditions along Line P in 2008 and early 2009

Marie Robert and Frank Whitney, Fisheries & Oceans Canada

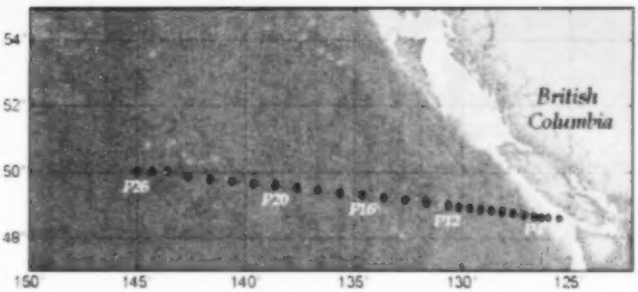


Figure 1. Line P and Ocean Station Papa (P26)

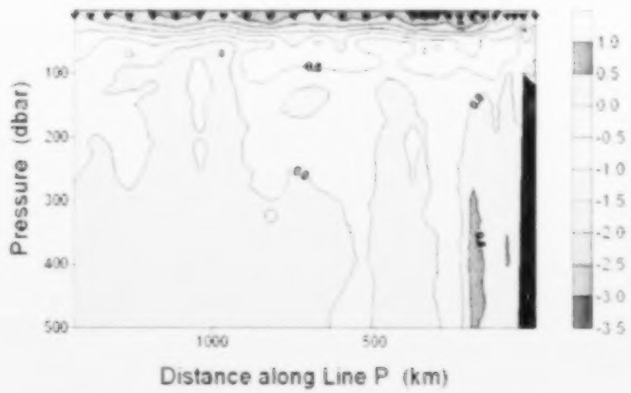


Figure 2. Temperature anomaly field along Line P in June 2008 compared to the 1956-1991 average

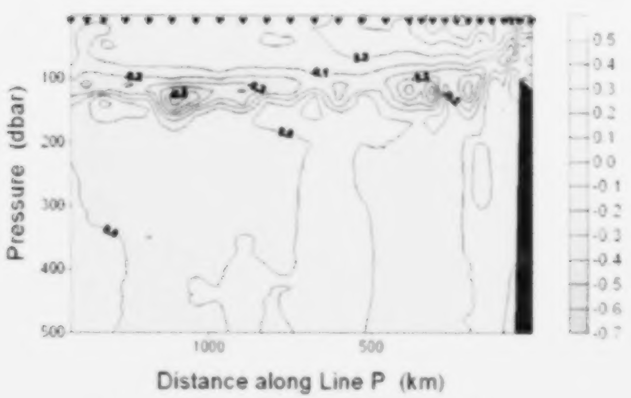


Figure 3. Salinity anomaly field along Line P in Aug. 2008 compared to the 1956-1991 average.

Line P is a series of ocean stations extending from the mouth of the Juan de Fuca Strait south of Vancouver Island to Ocean Station Papa at 50°N 145°W. (Fig. 1). The Line P time series is one of the longest deep-sea time series in the world, with data back to 1956. Research vessels of Fisheries & Oceans Canada visit Line P three times per year, usually in February, June, and August.

2008 was a cold year along Line P, both with respect to the long-term average (1956 – 1991) as well as with respect to recent years (2001 – 2007). The temperature anomaly at the surface reached -3.2°C in June 2008 compared to the long-term average (Fig. 2), and almost -4°C compared to the temperatures of the most recent warm year, 2005. This cold anomaly was evident during each cruise in 2008 (Feb., Jun. and Aug.)

The waters along Line P in 2008 were generally fresher than the long-term average except for the inshore surface waters, which were much saltier (Figure 3). The salinity anomaly between 100 and 125 metres depth shows a freshening of the top of the halocline, an indication of deeper wind-forced mixing which probably occurred in late winter. This anomaly is seen both in June and August 2008, and likely explains higher nutrient levels in the mixed layer in winter.

Because the surface waters were colder, the concentration of dissolved oxygen in surface waters was greater than during the last decade, but below a depth of about 100 meters declines in dissolved oxygen were observed.

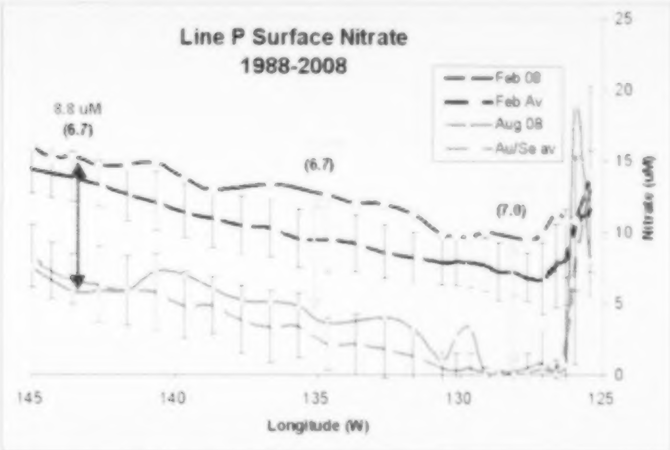


Figure 4. Surface nitrate values for 2008 and 1998-2008 averages. Numbers above arrows show the drawdown of nitrate in 2008 (colours) and the average over the past 20 years for three regions along Line P.

Fig. 4 shows the average of surface nitrate in February 2008 (black solid line) compared to the February average from 1998-2008 (black dashed line), as well as the August 2008 nitrate concentrations (red solid line) compared to the August average for the same period (grey dashed line). Not only were the surface nitrate concentrations higher than average, the nitrate drawdown was also much larger than during the last 20 years, which indicates strong primary productivity.

The temperature anomaly in February 2008 (Figure 5) compared to the 1956-1991 average shows a combination of slightly warmer (far from shore) and slightly colder waters (near shore) than the 1956-1991 values, but no extreme anomalies were seen.

The waters along Line P were still fresher than the 1956-1991 average.

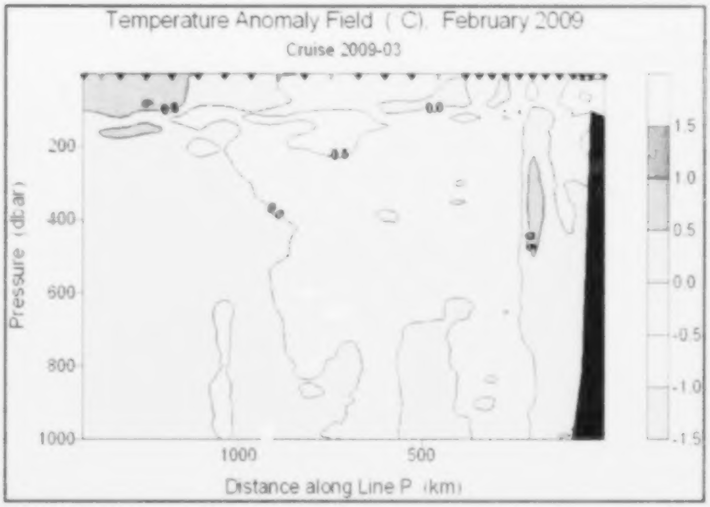


Figure 5. Temperature anomaly field (°C) along Line P in February 2009 compared to the 1956-1991 average.

Cold ocean temperatures at offshore weather buoys

Jim Gower, Fisheries & Oceans Canada

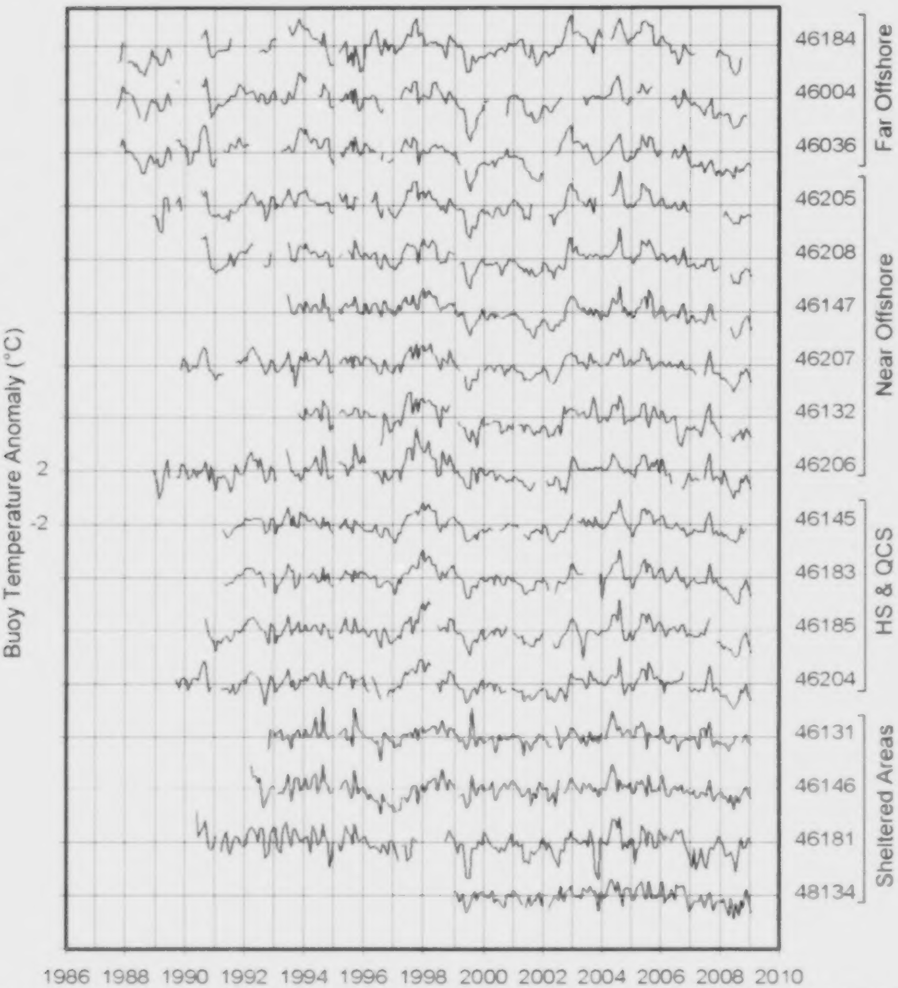


Figure 1. Time series of monthly sea surface temperature anomalies (SSTa) from the 17 ODAS buoys making up the weather buoy array on the west coast of Canada updated through 2008. The first 13 buoys are in 3 north-to-south lines, 46184 to 46036, 400 km offshore, 46205 to 46206 just off the coast of the Queen Charlotte and Vancouver Islands, and 46145 to 46204 in sheltered waters of Hecate Strait and Queen Charlotte Sound. The last 4 buoys are in more sheltered waters. Horizontal lines are separated by 4°C.

In Figure 1, all buoys show 2008 as a relatively cold year. For the first 13 buoys, the average of all months was 1.2°C colder than the average over their 10- to 20-year records. For buoys in sheltered inlets 2008 was 0.6°C colder. For May to August 2008 only, these anomalies were 1.6° and 0.8°C colder, respectively. The weather buoy program is funded by Environment Canada and Fisheries & Oceans Canada.

Northeast Pacific Ocean temperature for spring of 2009

Skip McKinnell, North Pacific Marine Sciences Organization (PICES)

Since the beginning of the 20th century, the climate of the NE Pacific has undergone transitions between cool and warm phases. Two notable cool periods occurred during the 20th century, one in the early 1900s and one in the early 1970s. These periods were characterized by persistently cooler-than-average temperatures in the atmosphere and the ocean and higher-than-average atmospheric pressures in the region. Figure 1 plots this time series.

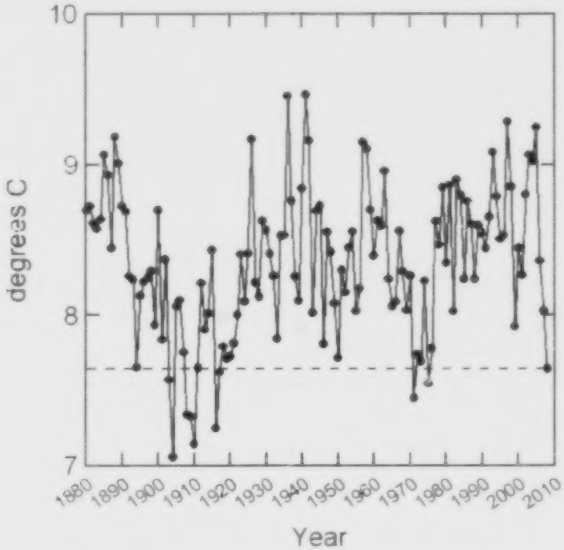


Figure 1. Area-weighted annual average SST for the Gulf of Alaska defined as east of 155°W, north of 50°N computed from the NOAA Extended Reconstructed SST database).

The area-weighted annual average SST for 2008 fell to a level observed only in these two previous cold periods (dashed line in Figure 1). The last time that an annual average SST was as cold as 2008 was in 1972 (36 years ago). McKinnell & Crawford (2007) reported that cold winters tend to follow 2 years after the peak of the 18.6 y lunar nodal cycle.

The peak occurred in 2006, so the observations of 2008 are consistent with an expectation developed from their model. Between September and October 2007, the high-resolution PDO shifted from "PDO-neutral" to negative (Figure 2).

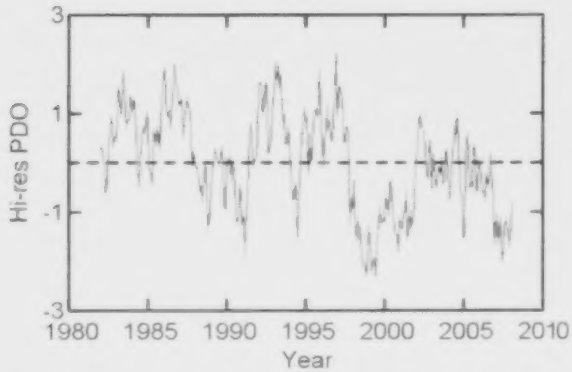


Figure 2. EOF 1 computed from NOAA/1°x1° optimally interpolated SST Version 2. (in McKinnell & Mantua, in prep.)

The DFO State of the Ocean report for 2007 included an outlook (McKinnell, 2008), based on this high resolution PDO, that the current cold phase would persist for several years (but may include a transient phase reversal some time during this period, as has occurred in all previous phases since the 1980s). The cooler waters of the NE Pacific in 2008 are in agreement with this prediction. I expect this negative (cool) phase will likely continue for at least one more year, with no El Nino in 2009/10.

There is a strong atmospheric teleconnection between air pressures in the western tropical Pacific (WTP) in winter (December to January) and ocean temperature in the NE Pacific in the following April. The U.S. NOAA/NCEP re-analysis data makes it possible to construct an index

of December/January sea level pressure over the western tropical Pacific (WTP) and use this as a basis for making an outlook of spring climate in the NE Pacific, as represented by ocean temperature at Kains Island off northwest Vancouver Island. When air pressure is low in the WTP, indicating enhanced Walker/Hadley circulation in the tropics, generally during La Nina-like conditions, the NE Pacific is cool. Furthermore, when the North Pacific is in one of its cool phases (e.g. 1969-1975), most of the SST anomalies at Kains Is. lie below the line by about 0.5°C. The intersection of the left dashed line in Fig. 3 with the fitted line was the forecast for 2008 and the black symbol labelled '8' was the observed SST for that year. It suggests that the forecast for spring 2009 based on recent SLP from the tropics (right dashed line) will likely lie below the fitted line as well, so the outlook for April 2009 is ~8°C. As SST at Kains Is. tends to be highly autocorrelated (values next month can be predicted from this month), it suggests a cool-average spring/summer on the west coast, but certainly not warm.

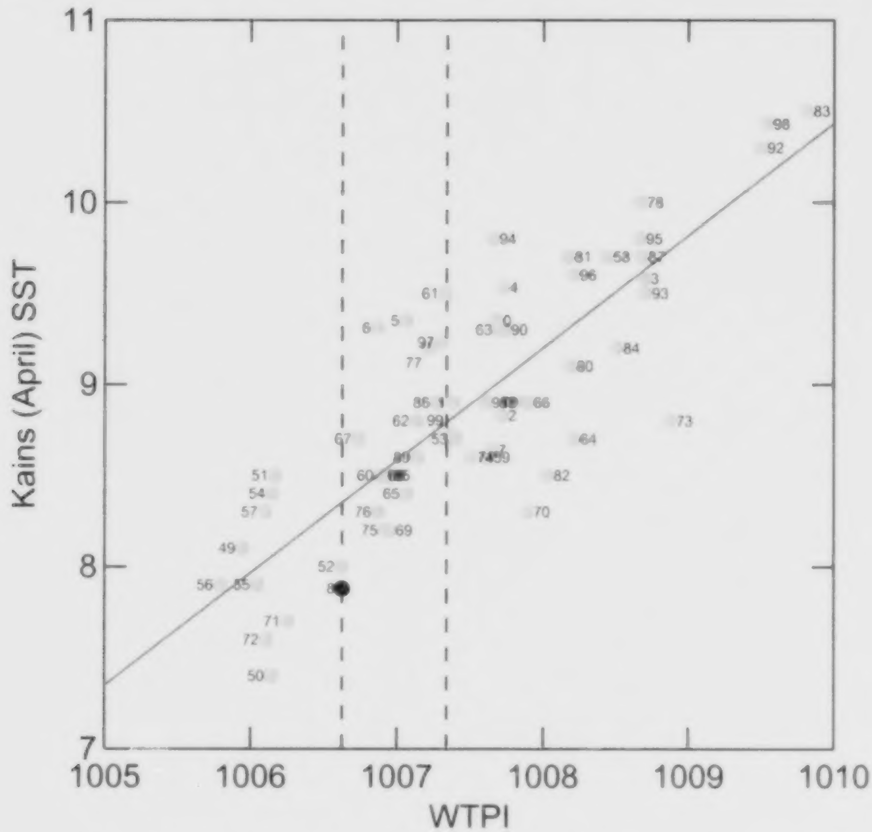


Figure 1. Average April ocean surface temperature (°C) at Kains Is. Lighthouse versus average sea surface pressure in the previous average December and January over the Solomon Sea in the western tropical Pacific Ocean. The vertical dashed lines indicate index values for 2008 (left) and 2009 (right). Their intersection with the blue line provide temperature predictions for April 2008 and 2009. The black circle represents actual April temperature in 2008 at Kains Island.

Most phytoplankton ever observed by satellite in Aug. 2008

Jim Gower, Fisheries and Oceans Canada

Figure 1 below shows the high chlorophyll levels observed by satellite sensors over the Gulf of Alaska in August 2008 (bottom left), compared to the same month in 2007 (top left). Chlorophyll concentrations were clearly higher in August 2008 in deep-sea regions of the gulf. In other years back to 1998, the chlorophyll levels have been comparable to the top left image.

The right-hand images show relative water brightness in August 2008 (bottom) and 2007 (top), also showing higher amounts of near-surface phytoplankton in August 2008. Bright blooms in the Gulf of Alaska are usually due to presence of coccolithophores whose high concentrations of carbonate reflect white light.

A graph on the next page reveals that August 2008 chlorophyll concentrations were the highest in the decade-long record. Chlorophyll concentration is an excellent indicator of the biomass of phytoplankton, and of the availability of plant food for the entire marine food chain.

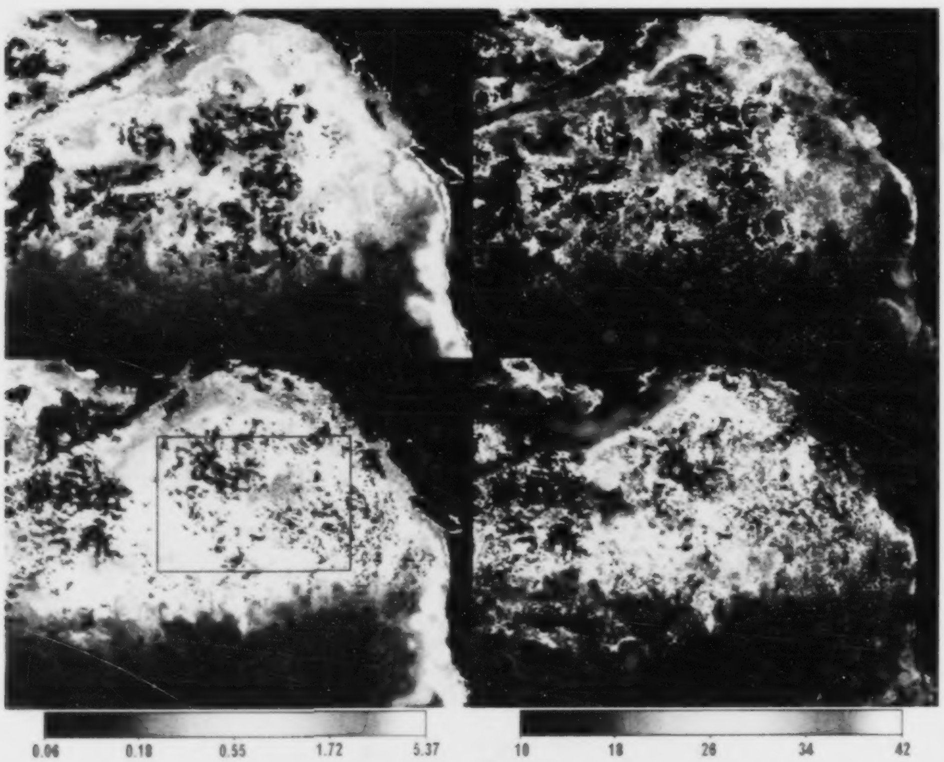
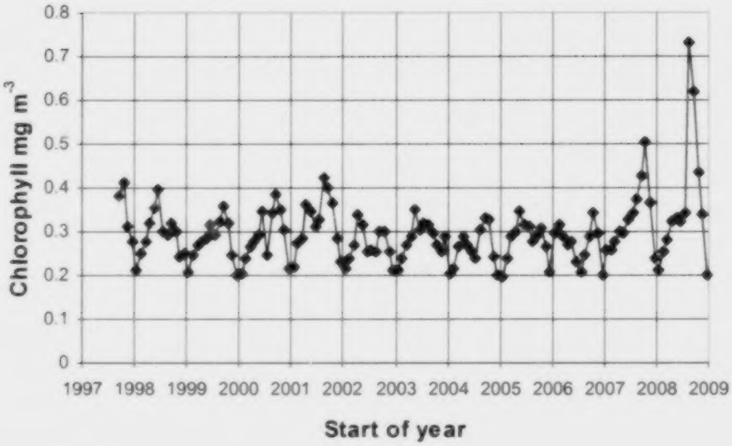


Figure 1. Monthly composite chlorophyll (left) and water brightness (right) for August 2007 (top) and August 2008 (bottom). Data are derived from the SeaWiFS and MODIS global composites at 9 km spatial resolution. Colour bars show values for the chlorophyll images (left) in mg.m-3 and for normalized water-leaving radiance at 555 nm (right) in W.m-2 micron-1 sr-1. The black-bordered box in the lower left image shows the area averaged to produce Figure 2.



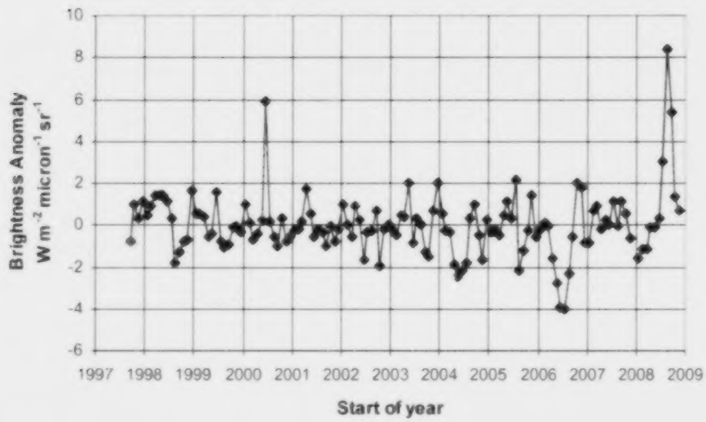


Figure 2. Time series of monthly chlorophyll (top) and monthly water brightness anomaly (significant annual cycle) (bottom) for the area 44° to 55°N, 134° to 155°W in the Gulf of Alaska for all months since the launch of SeaWiFS. Data for 2008 are from MODIS on Aqua and are available at http://oceancolor.gsfc.nasa.gov/.

SeaWiFS satellite data provide time series of chlorophyll and water brightness (normalized water-leaving radiance at 555 nm) for all months back to September 1997. In 2008, SeaWiFS data became intermittent, but the times series can be filled using equivalent data from MODIS on the Aqua satellite. These satellites and their data products are funded by NASA.

Figure 2 shows the result of computing average values over the rectangular area covering the longitude range 134°W to 155°W and the latitude range 44°N to 55°N (Figure 1, lower left) for all months, and subtracting the average annual cycle to give chlorophyll and brightness values. August 2008 gives the largest anomaly value so far in both time series. The previous high brightness peak in June 2000 was due to high concentrations of coccolithophores, which did not result in a significant peak in surface chlorophyll.

Mesozooplankton: Subarctic populations dominate in 2008

Sonia Batten, Sir Alister Hardy Foundation for Ocean Science, UK

Sampling was somewhat restricted in 2008, nevertheless clear signals in phenology (a shift to later peak timing) and species composition (a dominance by large copepods) indicate that the cooling of the northeast Pacific has resulted in a return to typical subarctic plankton populations seen at the start of the century. Total mesozooplankton biomass for the offshore BC region (from the continental slope to 145°W and between 48°N and 55°N) shows that June biomass was higher than May (in contrast to 2003-07 where May was the peak month) and that the August 2008 samples had exceptionally high biomass compared to previous years. (Fig. 1, though data for summer 2008 are provisional at this time).

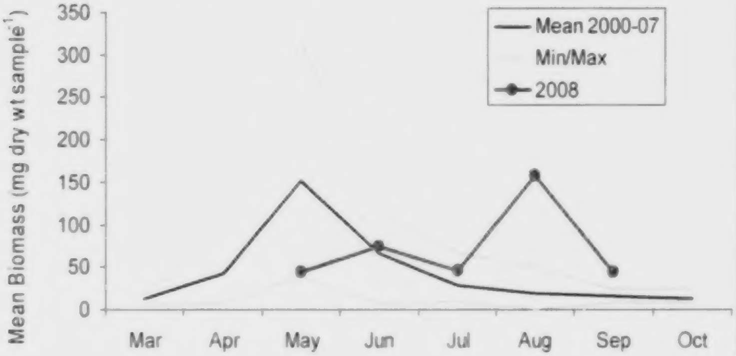


Figure 1. Mean monthly biomass for 2008, together with monthly mean, minimum and maximum mesozooplankton biomass (2000-07) in mg dry weight per sample (~3m^3) from Continuous Plankton Recorder sampling (which occurs approximately monthly 6-9 times per year, between March and October) in the off-shore Gulf of Alaska area. Data for summer 2008 are preliminary.

During cool years (2000, 2001 and 2008) the large copepods are more abundant in the summer (a combination of later development and doing better under cool conditions) but this was particularly striking in 2008 (Fig 2). *Neocalanus cristatus* (an exceptionally large calanoid copepod) had highest summer abundances recorded in the CPR time series in 2008 and this was augmented by later occurrences of *N. plumchrus* as well as *Calanus pacificus* being present in reasonable numbers. Conversely, small copepods are more important in warm years (e.g. the start of El Nino conditions in 1997, and in 2005, which was particularly warm) and in 2008 were noticeably reduced – their biomass was on average only 0.1% of the total. Large copepods tend to be rich in lipids and are likely to be a better prey item for higher trophic levels.

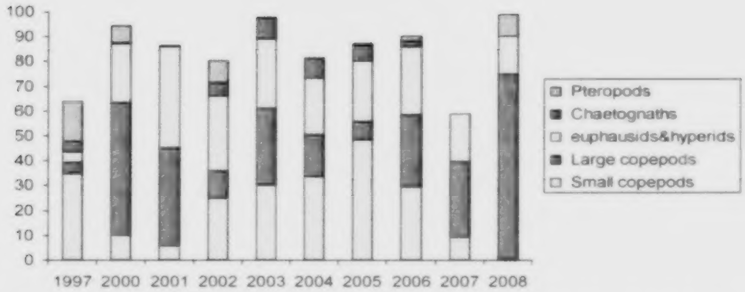


Figure 2. Mean biomass contribution of major taxonomic groups in July/August each year

http://pices.int/projects/tcprsotnp/default.aspx for data and more information.

Alaska's "Ecosystem Considerations for 2009" Report

Jennifer Boldt[1], Nick Bond[1], Terry Hiatt[2], Carol Ladd[3], Pat Livingston[2], Franz Mueter[4], John Olson[2], Jim Overland[4], Julie Pearce[2], Chris Rooper[2], Dan Urban[2], Carrie Worton[5]

[1]Joint Institute for the Study of the Atmosphere and Ocean, University of Washington
[2]National Marine Fisheries Service;
[3]Pacific Marine Environmental Laboratory
[4]University of Alaska Fairbanks, School of Fisheries and Ocean Sciences
[5]Alaska Department of Fish and Game

In Alaska, ecosystem pressure and state indicators are assessed annually in the Ecosystem Considerations Report (e.g. Boldt 2008; http://access.afsc.noaa.gov/reem/ecoweb/index.cfm.) Its intent is to update, summarize, and synthesize historical climate and fishing effects on the shelf and slope regions of the eastern Bering Sea/Aleutian Islands and Gulf of Alaska from an ecosystem perspective and to assess possible future effects of climate and fishing on ecosystem structure and function. Recent information specific to the Gulf of Alaska (GOA) is summarized here for DFO's "State of the Ocean" report: Climate and Physical Environment Trends

In the North Pacific, interannual variability, measured by El Nino/Southern Oscillation (ENSO) indices, and decadal scale variability, seen in the Pacific Decadal Oscillation index (PDO) are some of the more important climate influences on the GOA (Bond and Overland 2008).

1. Near-neutral ENSO conditions became established in the summer of 2008, changing to La Nina conditions in the late fall 2008 and winter 2009. La Nina conditions are expected to continue into spring 2009 (Bond and Overland 2008,

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.pdf

2. Large-scale climate factors resulted in relatively cool sea surface temperatures in mid Gulf of Alaska in the fall 2007 through spring 2008 and cool air temperatures in the coastal GOA during spring and summer of 2008, which probably implies somewhat delayed snowmelt, and depressed glacial melt (Bond and Overland 2008).

3. Sea-level pressure (SLP) patterns promoted enhanced westerly winds across most of the northern portion of the Gulf of Alaska during fall 2007 through spring 2008. The prevalence of westerly wind anomalies resulted in an increase in the North Pacific Current in the eastern North Pacific. Since the flow in the California Current System was also stronger relative to past years, while the flow in the coastal GOA did not change much, the proportion of the flow across the Pacific entering the Alaskan Current and GOA was lower than normal (Bond and Overland 2008).

4. In the GOA there are three regions of local maxima eddy kinetic energy, two of which are associated with formation of Haida and Sitka eddies. Eddies that move along the shelf-break often feed into the third region of high eddy kinetic energy. In this third region, where eddies impinge on the shelf east of Kodiak Island in spring, higher eddy kinetic energy values were observed in the spring of 2007 and 2008. This implies phytoplankton biomass likely extended farther off the shelf and cross-shelf transport of heat, salinity, and nutrients (such as iron, nitrate, silicate) may have been greater than in 2005-2006 (Ladd 2008).

Climate Effects on Ecosystems and Ecosystem Trends in US waters

1. There is strong indication for above-average groundfish recruitment (as indexed by a standardized index of recruitment) in the GOA management area (the 200-mile U.S. Exclusive Economic Zone of the United States) during 1994-2000 and below-average recruitment since 2001 (Mueter 2008a).

2. Overall groundfish annual surplus production (an estimate of the sum of new growth and recruitment minus deaths from natural mortality in a year) in the GOA has been relatively stable, with no significant linear trend during 1977-2006 (Mueter 2008b).

3. The mean-weighted distribution of GOA rockfish (1990-2007), especially juvenile Pacific ocean perch (POP), appeared to be farther north and west and was more contracted in 2007 relative to previous years (1990-2005), possibly indicating a change in rockfish distribution around the GOA (Rooper 2008).

4. The 2007 GOA Alaska Department of Fish and Game (ADFG) large mesh survey caught a record number of Tanner crabs in Ugak Bay since consistent sampling began in 1988. Arrowtooth flounder continues to be the main component of offshore catches (mt/km), while Tanner crab and flathead sole were the largest catches (mt/km) inshore. Also, Pacific cod catch rates (mt/km) were noticeably low inshore in 2007 relative to past years (1988-2006; Worton 2008).

5. The GOA ADFG and NOAA small-mesh survey showed a transition from a community rich in shrimp and capelin to a community rich in groundfish, following the onset in 1976/1977 of the warm phase of the Pacific Decadal Oscillation (Anderson and Piatt 1999). Catches through 2007 do not show any significant deviation from this groundfish-dominated community (Urban 2008).

Fishing Effects on Ecosystems in US waters

- No groundfish stock is considered overfished or subjected to overfishing.
- Discards and discard rates have remained below those observed prior to 1998, when regulations were implemented prohibiting discards of pollock and cod (Hiatt 2008a).
- In 2007, GOA bottom trawl effort increased; whereas, other gear effort remained relatively stable (Olson 2008a-d).
- The numbers of hook and line vessels participating in the groundfish fisheries off Alaska have decreased over the last 4 years (2004-2007); whereas, the numbers of pot and trawl vessels have remained relatively stable over the last four years (2004-2007; Hiatt 2008b).

Literature cited

Anderson, P. J., and J. F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series 189: 117-123.

Boldt, J.L. (editor). 2008. Ecosystem Considerations for 2009. Appendix C of the Bering Sea/Aleutian Islands and Gulf of Alaska Groundfish Stock Assessment and Fishery Evaluation Report. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501. 217p.

Contributions in the Ecosystem Considerations for 2009 report (i.e. Boldt 2008):

Bond, N., and J. Overland. 2008. North Pacific climate overview. P. 26-36.

Hiatt, T. 2008a . Time trends in groundfish discards. P. 144-145.

Hiatt 2008b. Groundfish fleet composition. P. 186.

Ladd, C. 2008. Eddies in the Gulf of Alaska – FOCI. P. 39-41.
Mueter, F. 2008a. Combined standardized indices of recruitment and survival rate. P. 141-143.
Mueter, F. 2008b. Total annual surplus production and overall exploitation rate of groundfish. P. 174-176.
Olson, J. 2008a. Hook and line (longline) fishing effort in the Gulf of Alaska, Bering, Sea and Aleutian Islands. P. 147-152.
Olson, J. 2008b. Groundfish bottom trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands. P. 153-157.
Olson, J. 2008c. Groundfish pelagic trawl fishing effort in the Gulf of Alaska, Bering Sea and Aleutian Islands. P. 158-162.
Olson, J. 2008d . Pot fishing effort in the Gulf of Alaska, Bering Sea, and Aleutian Islands. P. 163-167.
Rooper, C.N. 2008. Distribution of rockfish species along environmental gradients in Gulf of Alaska and Aleutian Islands bottom trawl surveys. P. 62-65.
Urban, D. 2008. Gulf of Alaska small mesh trawl survey trends. P. 98-100.
Worton, C. 2008. ADF&G Gulf of Alaska trawl survey. P. 94-98.

WEST COAST BRITISH COLUMBIA

Wind-driven upwelling along the west coast

Roy Hourston and Richard Thomson, Fisheries & Oceans Canada

Ocean current velocity, along with water temperature and salinity, have been measured continuously since 1985 at mooring A1, located at 48° 32'N 126° 12'W in 500 m of water on the continental slope seaward of La Pérouse Bank (Figure 1). Sea surface temperature, wind velocity, and other meteorological properties have been measured since 1988 at a nearby Environment Canada buoy 46206 (48° 50'N 126° 00'W). These records enable us to characterize interannual variability of meteorological and physical oceanographic conditions off the west coast of Vancouver Island.

Figure 2 shows the timing of the spring transition off La Pérouse Bank based on the alongshore current velocity at A1 at 35 m depth and the alongshore surface wind stress at meteorological buoy 46206. The spring transition marks the shift from poleward to equatorward ocean current and the beginning of biologically productive spring-summer upwelling conditions. The large-scale features of the shelf break current are wind-driven, although the spring transition of the ocean current at A1 typically leads the wind by roughly two and a half weeks due to non-local effects.

Years having a late spring transition, such as 2003 and 2005, have been characterized by poor or significantly altered productivity in plankton, fish and birds, as documented in earlier State of the Ocean reports. Based on these data, it appears that the spring transition timing for the coastal ocean current in 2008 was (like 2007) one of the earlier on record, a remarkable change from 2005 when the transition was the latest recorded in our time series. Early transition years such as 2008 tend to favour enhanced biological productivity along the coast.

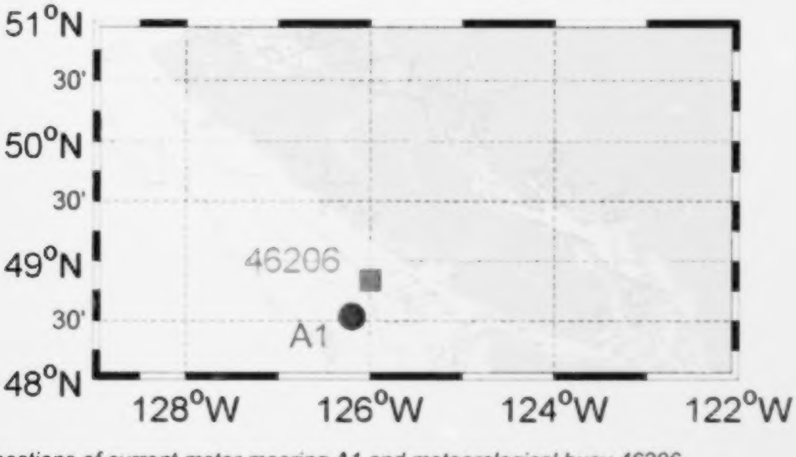


Figure 1. Locations of current meter mooring A1 and meteorological buoy 46206.

Due to their link with upwelling currents, the duration and intensity of upwelling-favourable winds are generally considered indicators of coastal productivity. To gauge low-frequency variability in coastal productivity, we have summed upwelling-favourable-only winds (from NCEP/NCAR Reanalysis-1, Kistler et al., 2001) by month along the west coast of North America from 45°-60°N latitude (Figure 3). Monthly mean anomalies smoothed using a five-year running mean for

the period 1948-2009 are shown in Figure 4. Results clearly show the regime shift in the late 1970s as a sharp transition from stronger- to weaker-than-average upwelling-favourable winds. Upwelling-favourable winds have been stronger than average throughout the 2000s. In recent State of the Ocean Reports we speculated that a repeat of the 1977 regime shift to weaker-than-average upwelling appeared imminent. However, stronger-than-average upwelling-favourable winds continued through 2008 as far north as 55 °N, as shown by unsmoothed anomalies for the most recent years (Figure 5). These results are consistent with the alongshore current record at A1 at 35 m depth, which had a stronger equatorward component than average during 2007-2008.

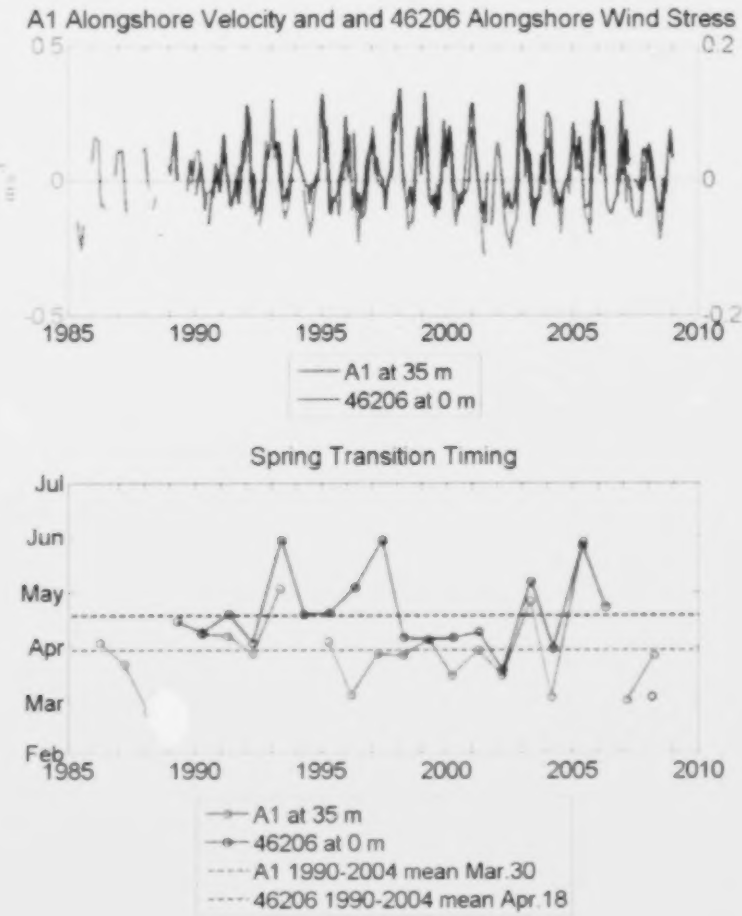


Figure 2. Spring transition timing of alongshore current velocity at mooring A1 at 35 m depth and alongshore wind stress at met buoy 46206. Timing was derived from when the monthly mean time series crossed the zero line (poleward to equatorward) in the spring. In the case of multiple crosses in one year, the times were averaged to obtain one value per year. The timing estimate for 46206 wind stress in 2007 is poor due instrument failure in the spring.

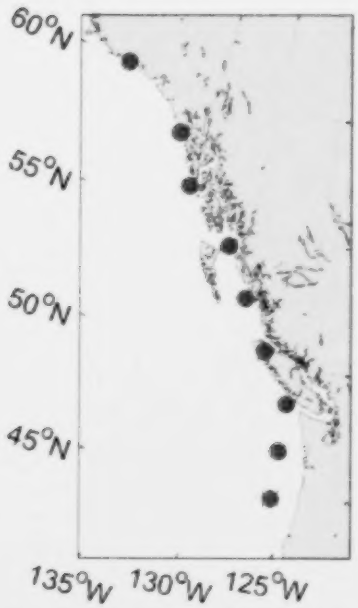


Figure 3. NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations.

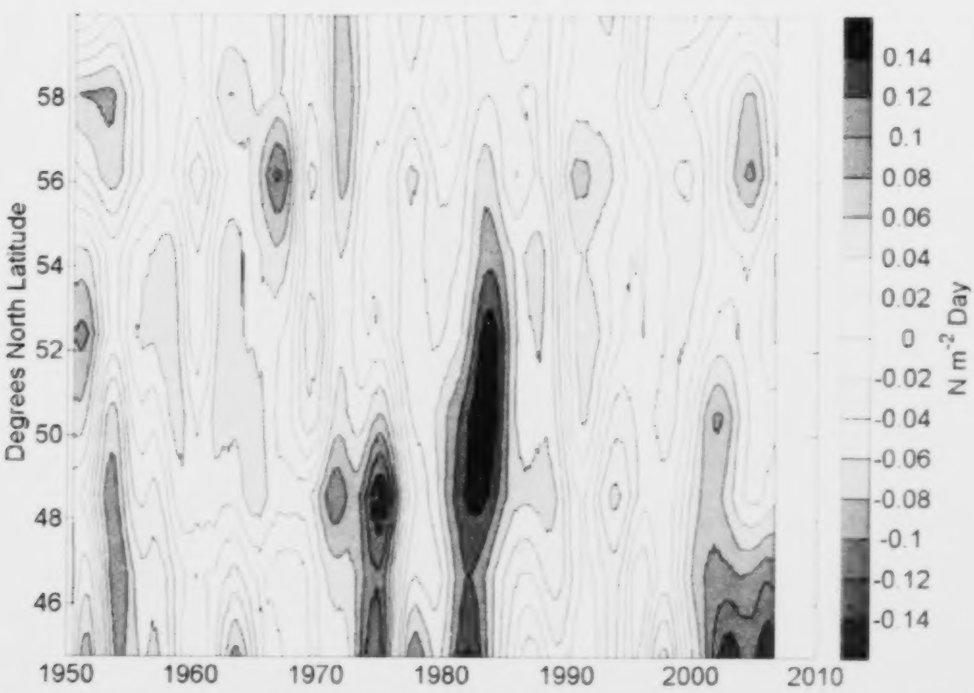


Figure 4. Five-year running-means of monthly mean anomalies of monthly sums of alongshore upwelling-favourable (equatorward) wind stress at coastal grid points from 45°N to 60° N.

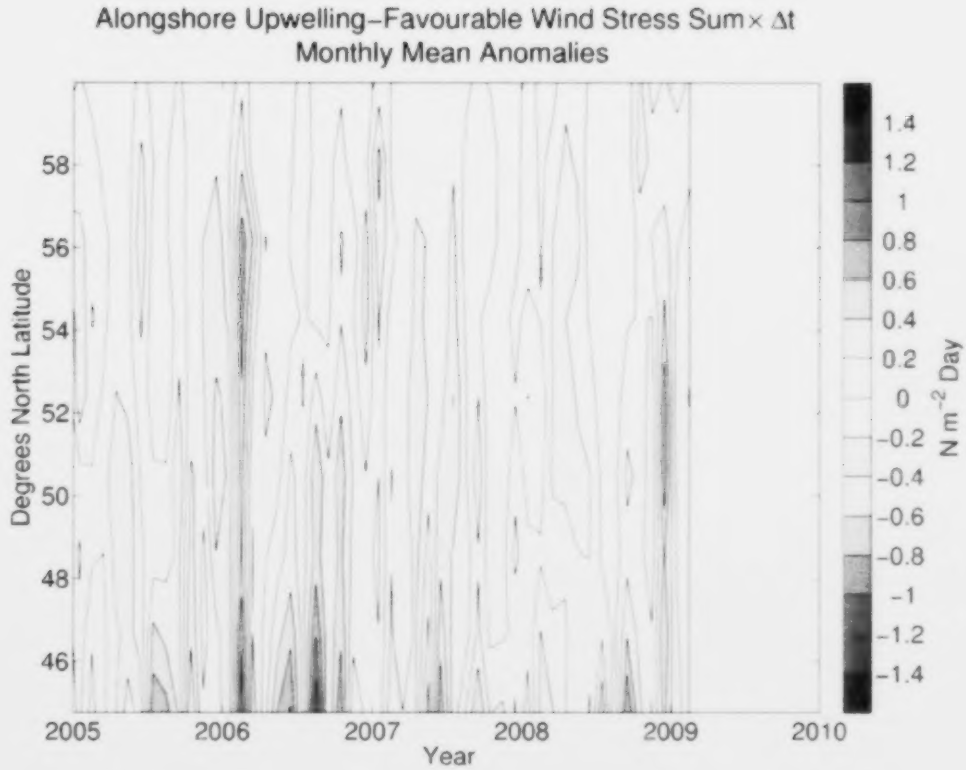


Figure 5. Recent (2005 to 2009) non-filtered monthly mean anomalies of monthly sums of alongshore upwelling-favourable (equatorward) wind stress at coastal grid points from 45°N to 60°N.

Acknowledgements

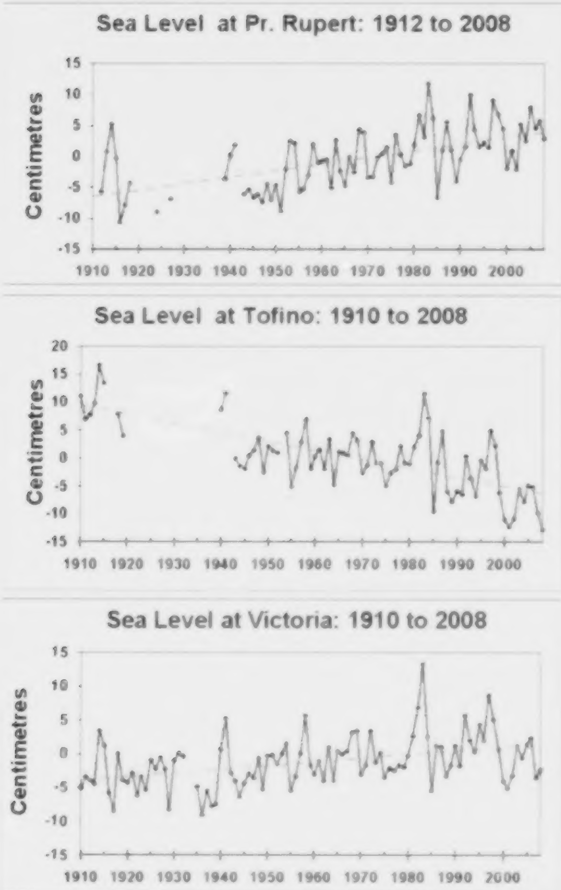
NCEP Reanalysis data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/

Reference

Kistler, R., Kalnay, E., Collins, W., Saha, S., White, G., Woolen, J., Chelliah, M., Ebisuzaki, W., Kanamitsu, M., Kousky, V., van del Dool, H., Jenne, R., Fiorino, M. 2001. The NCEP–NCAR 50-year reanalysis: monthly means CD-ROM and documentation. Bulletin of the American Meteorological Society 82: 247–267.

Coastal sea levels: Below normal in 2008 in southern BC.

Bill Crawford, Fisheries and Oceans Canada



The Canadian Hydrographic Service monitors sea level along the coast. The records at left show deviations from long-term average levels at three BC ports. Stronger winter winds from the west dropped sea levels below normal in southern BC in 2008.

Dashed red lines show the linear trend over the record length. These trends are listed below (in cm/century):

Prince Rupert	+11
Victoria	+6
Tofino	-16

Tectonic motion is lifting the land at Tofino faster than sea level is rising, so local sea level is actually dropping at a rate of 16 cm per 100 years. The next Cascadia Subduction Zone earthquake will drop the land at Tofino and along the west side of Vancouver Island by a metre or so, and send a major tsunami toward this coast.

Figure 1. Graphs of annual-averaged sea level anomalies at three British Columbia ports. Long-term linear trends are plotted as red dashed lines.

Global sea level rose by 17± 5 cm in the 20th century. Satellite observations since 1993 indicate a global rise of 0.3 cm per year, which is 30 cm/century. The Intergovernmental Panel on Climate Change (IPCC 2007) predicts sea level to rise by 20 to 60 cm over the 21st century, but recent observations of ice melt in Greenland and Antarctica suggest these projections are too low, and the global sea level rise could possibly reach one metre.

Links: Canadian Hydrographic Service

(http://www-sci.pac.dfo-mpo.gc.ca/charts/home_e.htm)

Long-term temperature and salinity at BC lighthouses

Peter Chandler, Fisheries and Oceans Canada

Temperature and salinity are measured daily at the first daylight high tide by light keepers at 13 shore stations as part of the British Columbia Shore Station Oceanographic Program.

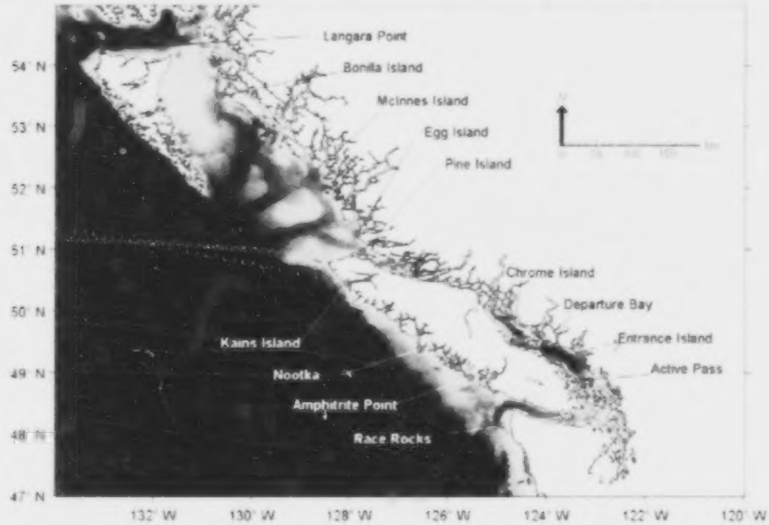


Figure 1. The 13 staffed stations presently in the network

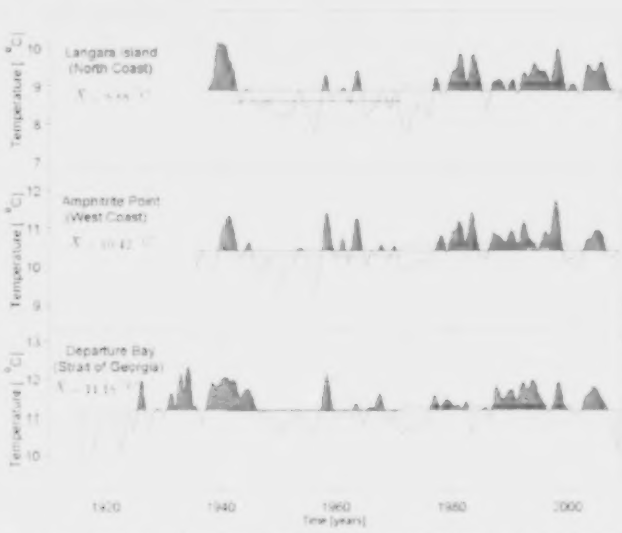


Figure 2. Long-term time series of annual-average temperature at representative stations in BC. Observations show temperatures close to or below the long-term average (where the average is calculated over the entire data record). The blue lines represent the average following the Environment Canada convention (30 y with the final year ending in a 1).

Long-term temperature and salinity at BC lighthouses

Peter Chandler, Fisheries and Oceans Canada

Temperature and salinity are measured daily at the first daylight high tide by light keepers at 13 shore stations as part of the British Columbia Shore Station Oceanographic Program.

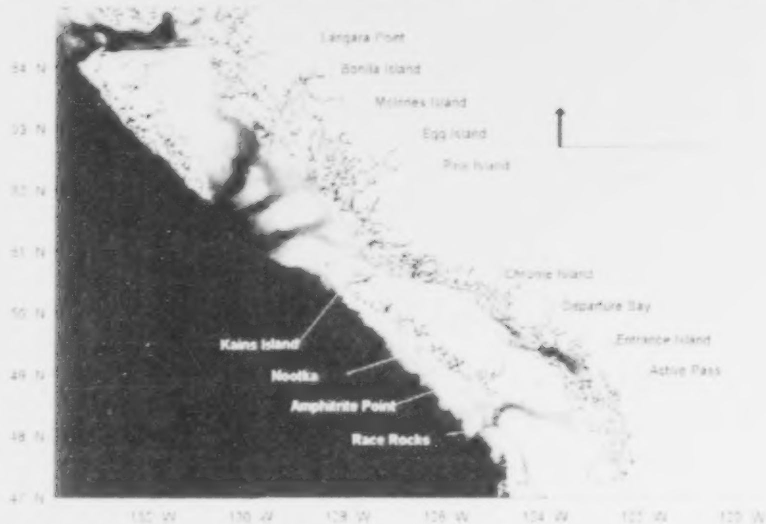


Figure 1. The 13 staffed stations presently in the network

Figure 2. Long-term time series of annual-average temperature at representative stations in BC. Observations show temperatures close to or below the long-term average (where the average is calculated over the entire data record). The blue lines represent the average following the Environment Canada convention (30 y with the final year ending in a 1).

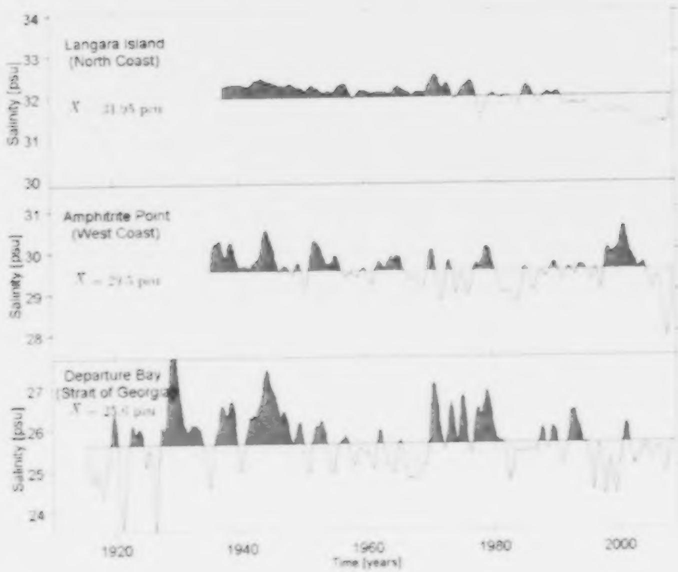


Figure 3. Long-term salinity time series at representative stations. Surface waters show a continuing freshening trend, especially at Langara Point.

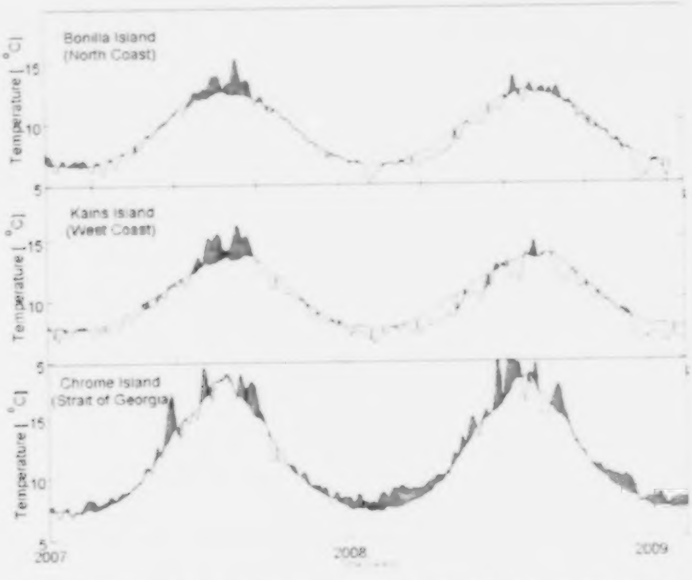


Figure 4. Temperature anomalies and the annual cycle (calculated from the 1971 – 2001 sea surface temperature data) at representative station). Surface waters on the north and west coasts show below-average temperatures throughout the year, with minor exceptions in mid-summer. Surface waters of the Strait of Georgia continue to have above-average temperatures.

Temperature Anomalies in 2008

Lower-than-average sea surface temperatures are observed at all north and west coast stations, although there was some warming along the west coast during the late fall. The Strait of Georgia stations show more variability, with the Departure Bay station having consistently lower-than-normal temperatures and Active Pass having consistently higher-than-normal temperatures in 2008.

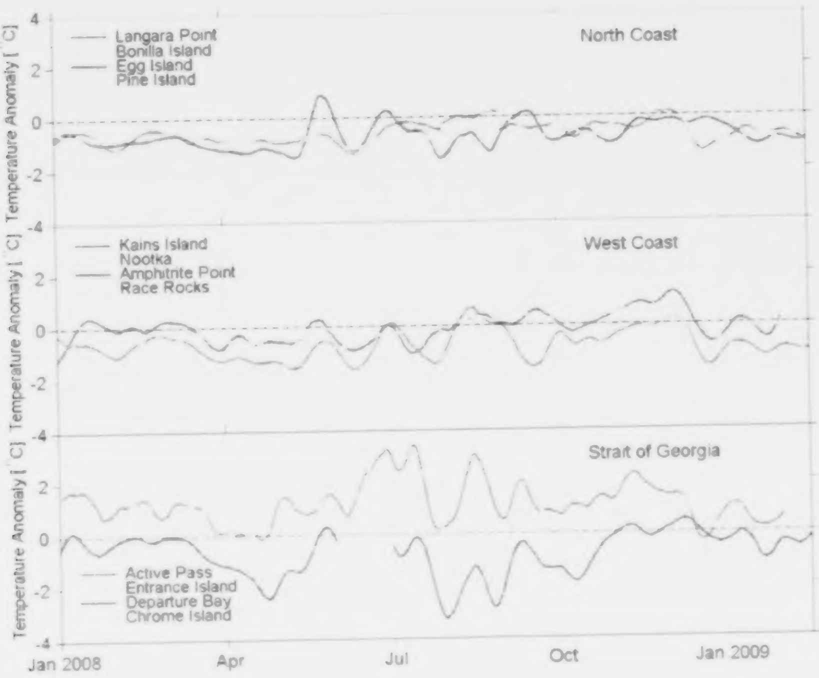


Figure 5. Time series of daily sea surface temperature anomalies relative to the long-term average calculated from daily observations made between 1971 and 2001.

Salinity Anomalies in 2008

Observations of sea surface salinity anomalies show close-to-average values in almost all regions, with fresher waters evident at Egg Island, and during the latter part of the year in the Strait of Georgia.

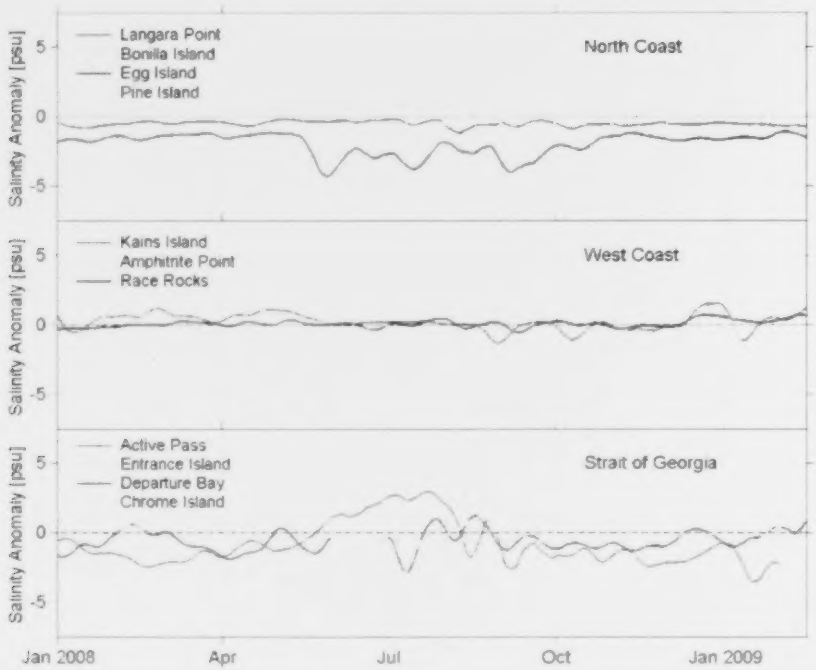


Figure 6. Time series of daily sea surface salinity anomalies relative to the long-term average calculated from daily observations made between 1971 and 2001.

Links: BC Seawater sampling at Lighthouses
(http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm)

Spreading hypoxia in deep waters along the west coast

Frank Whitney, Fisheries & Oceans Canada

"Hpoxia" is a term for critically low oxygen concentrations. Oxygen levels are declining toward hypoxia in waters at 100 to 500 metres below the ocean surface (Fig. 1), based on time-series measurements of at least 25 years collected in the open ocean at Ocean Station P, and along the Pacific coast of southern California (S CA), southern BC (WCVI) and the west coast of Queen Charlotte Islands in northern BC (WCQCI). Rates of decline exceed 1% per year in the 200 to 300 metre range in coastal waters, which presently contain 50 to 130 μM oxygen.

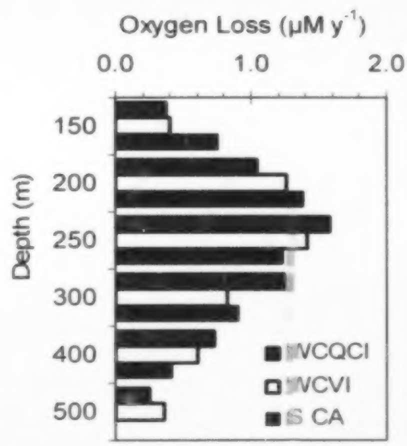


Figure 1. Rates of oxygen loss at three stations along the Pacific coast of North America.

Many other studies have remarked on the loss of oxygen in sub-surface waters of the subarctic Pacific, identifying the cause as weakening winter ventilation off the Asian coast due to a freshening and perhaps warming of the mixed layer. The warming trend is not as assured as freshening because of the large annual cycle.

As oxygen diminishes in coastal waters, there must be impacts on biological communities, since all animals require oxygen. Along the Oregon coast, low oxygen events have caused fish and crab kills at the ocean bottom within the last several years (Chan et al., 2008), events not observed in the past. Whitney and Sinclair (submitted) find that the deep habitat of the groundfish community along the BC coast has been decreasing in depth by 2 to 3 metres per year over the past decade (i.e. fish are moving to shallower waters). This rate of rise is the same as the observed rate of oxygen isopleth shoaling.

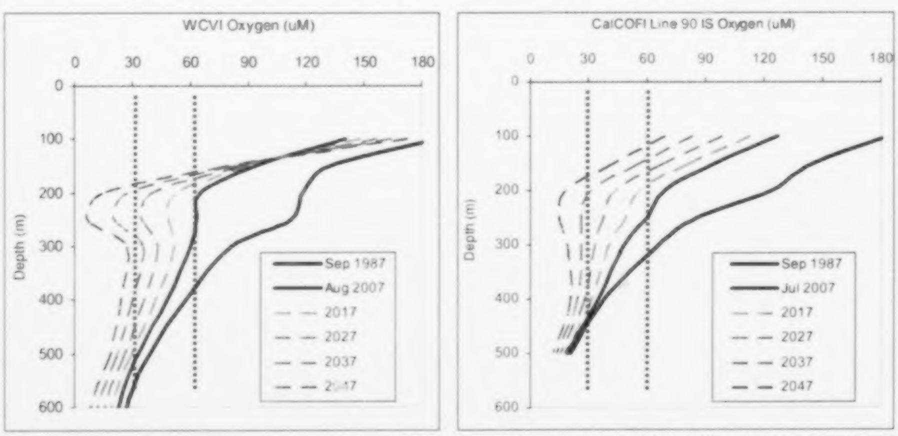


Figure 2. Oxygen concentrations in summer off the southern coast of California (CalCOFI data) and British Columbia (west coast of Vancouver Island), with measured levels for 1987 and 2007 shown as solid lines, and projected concentrations for the next few decades shown as dashed lines. Red arrows highlight the shoaling of 30 and 60 μM contours.

Oxygen is less plentiful in deep waters off California and is relatively abundant in the Gulf of Alaska. The 30 μM oxygen contour slopes along shore, deepening from about 450 m off California to about 650 m off southern Alaska. A simple linear extrapolation of oxygen levels, based on the past 25 years of data, suggests oxygen could be depleted in these deep waters off the BC coast by 2050 (Fig. 2).

As hypoxia continues to expand in these waters, hypoxic stress will be most acute to the south. Fish and other organisms unable to tolerate this stress will be forced either into shallower waters, or possibly into northward migrations. Hake biomass has been observed shifting northward from California (Benson et al, 2002) and invasions of Humboldt Squid have introduced this new, voracious predator into BC waters. However, we lack specific evidence linking these migrations to oxygen concentrations in deep waters.

A caveat to this prediction of lower oxygen concentrations is that ventilation of the deep-sea subarctic Pacific Ocean has varied in the past with the 18.6 year lunar nodal cycle (McKinnell and Crawford, 2007; Whitney et al., 2007). This is evident in waters found between 250 and 300 m depth in the 50-year record at Ocean Station Papa. Cool winters with the enhanced tidal mixing that accompanies a maximum of this cycle (2006 being a maximum) would increase the volume of oxygenated waters being supplied to intermediate depths of the subarctic Pacific. Recent data from Argo profilers indicate a broader outcropping of dense waters in the Bering Sea in winter 2009.

http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/argo/default_e.htm

As a consequence, in a decade or so, a pulse of oxygenated waters may be transported to the western coast of North America. However, since global warming is the root cause of the long-term oxygen decline discussed here, a winter or two with increased ventilation should only slow the anticipated declining trend in sub-surface oxygen concentrations.

References

Benson, A.J., McFarlane, G.A., Allen, S.E. and Dower, J.F. 2002. Changes in Pacific hake (Merluccius productus) migration patterns and juvenile growth related to the 1989 regime shift. Can. J. Fish. Aquat. Sci. 59, 1969–1979.

Chan, F., Barth, J.A., Lubchenco, J., Kirincich, A., Weeks, H., Peterson, W.T. and Menge, B.A. 2008. Emergence of anoxia in the California Current Large Marine Ecosystem. Science 319, 920.

McKinnell, S.M. and Crawford, W.R. 2007. The 18.6-year lunar nodal cycle and surface temperature variability in the northeast Pacific. J. Geophys. Res., 112, C02002, doi:10.1029/2006JC003671.

Whitney, F.A., Freeland, H.J. and Robert, M. 2007. Persistently declining oxygen levels in the interior waters of the eastern subarctic Pacific. Progr. Oceanogr. 75, 179-199.

Whitney, F.A. and Sinclair, A.F. submitted. Hypoxia along the Pacific Coast of North America and its impact on groundfish. Can. J. Fish. Aquat. Sci.

Oxygen decline in bottom waters off Vancouver Is. measured by trawling surveys

Alan Sinclair, Fisheries & Oceans Canada

Synoptic bottom-trawl surveys have been conducted bi-annually since 2004 off the west coast of Vancouver Island to monitor the abundance of groundfish species (Figure 1). Sensors attached to the trawl net were used to collect data on depth, temperature, and salinity in the 2004 survey, and an oxygen sensor was added in 2006. These sensors will be deployed on future surveys to monitor the impact of environmental conditions on species catches.

Environmental conditions in deep waters of the continental shelf differed between 2006 and 2008. Oxygen concentrations and temperature were lower and salinity was higher in 2008 than in 2006 (Figure 2). Most of the decrease in oxygen might be due to denser, oxygen-poor waters moving into shallow regions in 2008 than in 2006. Although a decline in oxygen concentration is consistent with the general trend in the northeast Pacific (Whitney et al. 2007, Whitney, this report), the change from 2006 to 2008 is more than expected, and is likely due to a response of sub-surface ocean currents to unusual winds and weather between 2006 and 2008.

Both surveys were conducted in May and June; there were 150 tows in 2006 and 137 tows in 2008. The surveys follow a depth-stratified, random design, and while the tow locations varied between years, the depth profile sampled was similar in both years.

Comparison of the median depth distribution of several species between the 2 surveys (Figure 3) indicates there was a shift in distribution toward shallower water in 2008. Thirty-five species were selected for comparison based on their relative abundance in the survey. The median depth of capture was estimated based on the cumulative distribution of their design-weighted catches (Smith et al. 1991). Of the 35 comparisons, 23 species were caught in shallower water in 2008 compared to 2006. The largest differences in median depth of capture were in the 100 – 200 m depth range. The three species caught in the shallowest waters did not change depth between the two years. While it is difficult to determine the cause of this shift in species distribution, it is tempting to conclude that it is related to reduced oxygen concentration, although reduced temperature could also be a factor.

Generally, oxygen concentrations in bottom waters off Vancouver Island are expected to be a minimum in summer, when upwelling winds pull deep, oxygen-poor waters onto the continental shelf and the organic material deposited by the spring bloom has oxidized. We rely on regular research cruises for samples of oxygen in this season, and have decades of measurements, although with fewer samples than provided by trawling surveys in spring in 2006 and 2008. Figure 4 presents a time series of these measurements, plotted versus depth of ocean bottom. All measurements were taken by titrating samples of water collected at these depths by ocean research projects, and are therefore very high-quality observations. Figure 4 suggests oxygen concentrations have been lower since 1996, in waters between 100 and 300 metres deep.

Future trends in oxygen concentrations will be due to long-term climate-related changes, and shorter-period weather-related impacts. Whitney (this report) notes a long-term decline in oxygen concentrations of 1% per year in the 100 to 200 m range on west coast Canadian shelf waters. This rate is much less then observed here between 2006 and 2008, so we anticipate oxygen levels over these depths will increase in the short term, over one to ten years, as the unusual winds and weather of 2006 to 2008 give way to more normal conditions.

References

Smith, S.J., Perry, R.I., and Fanning, L.P. 1991. Relationships between water mass characteristics and estimates of fish population abundance from trawl surveys. Environ. Monitor. Assess. 17: 227-245.

Whitney, F.A., Freeland, H.J., and Robert, M. 2007. Persistently declining oxygen levels in the interior waters of the eastern subarctic Pacific. Prog. Oceanogr. 75: 179-199.

Whitney, F., this report. Spreading hypoxia in deep waters along the west coast.

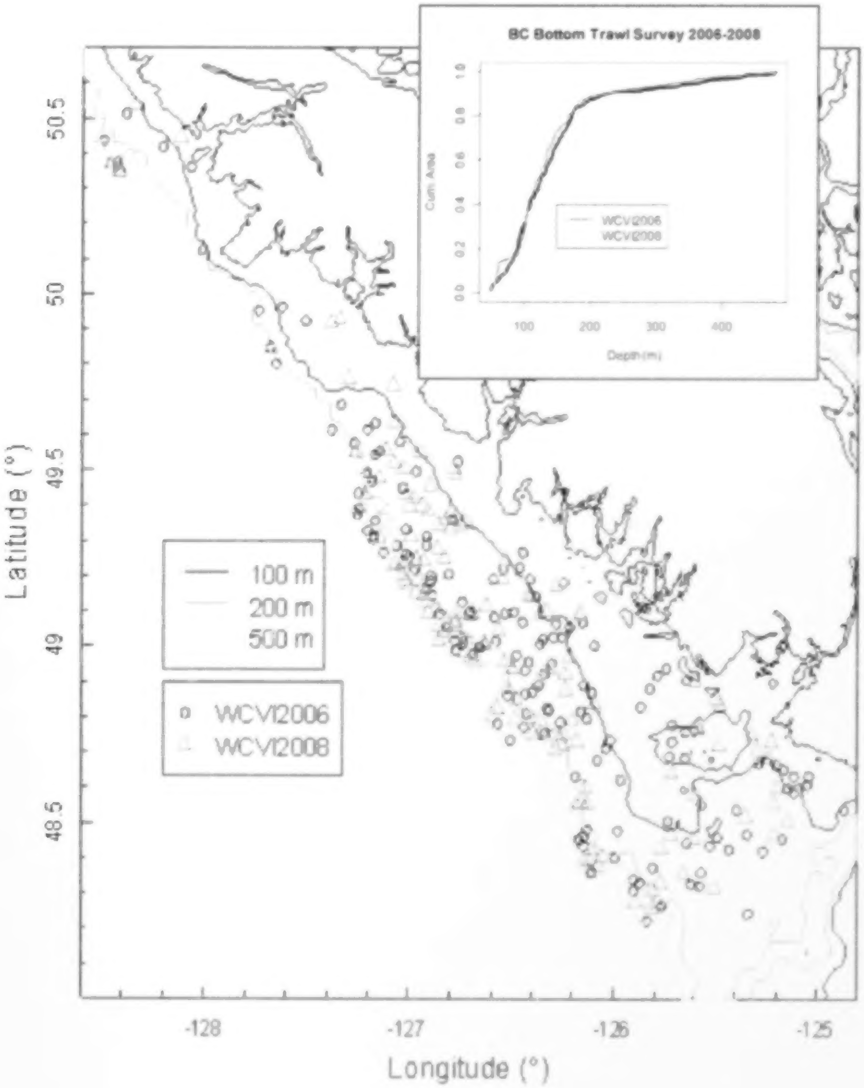


Figure 1: Tow locations of the 2006 and 2008 west coast Vancouver Island groundfish bottom trawl surveys. The insert shows the cumulative depth distribution of the tows in the 2 surveys.

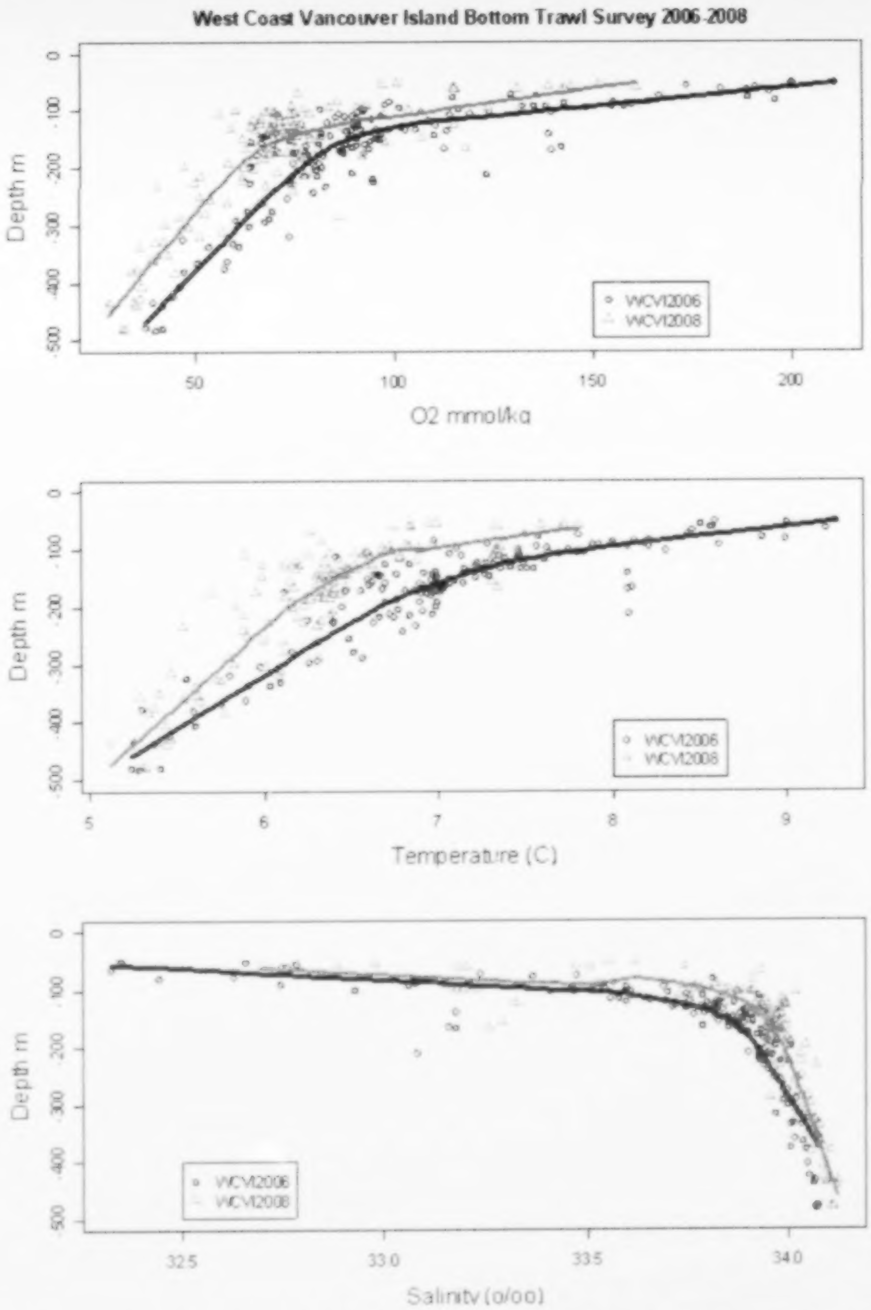


Figure 2: Oxygen, temperature and salinity vs. depth observed in the 2006 and 2008 west coast Vancouver Island groundfish bottom trawl surveys. Oxygen concentration and tempera-ture were lower and salinity was higher in 2008 compared to 2006.

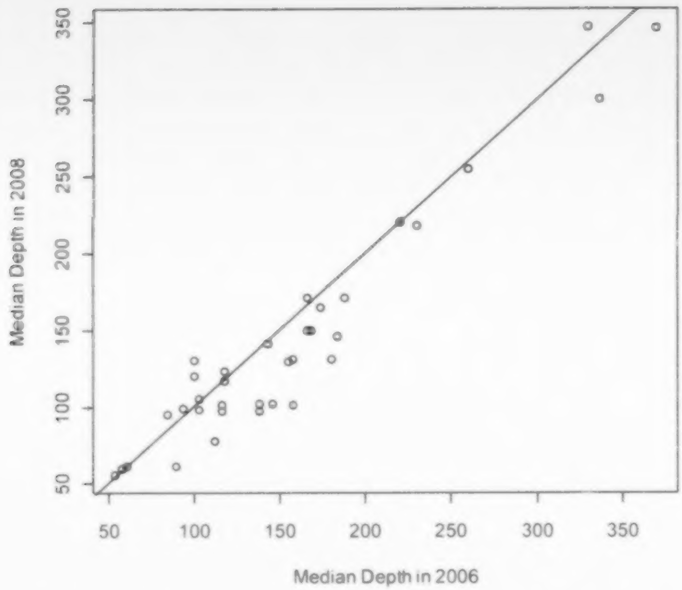


Figure 3: Median depths of 35 species caught in the 2006 and 2008 west coast Vancouver Island groundfish bottom trawl surveys. The majority of species were caught shallower in 2008 compared to 2006.

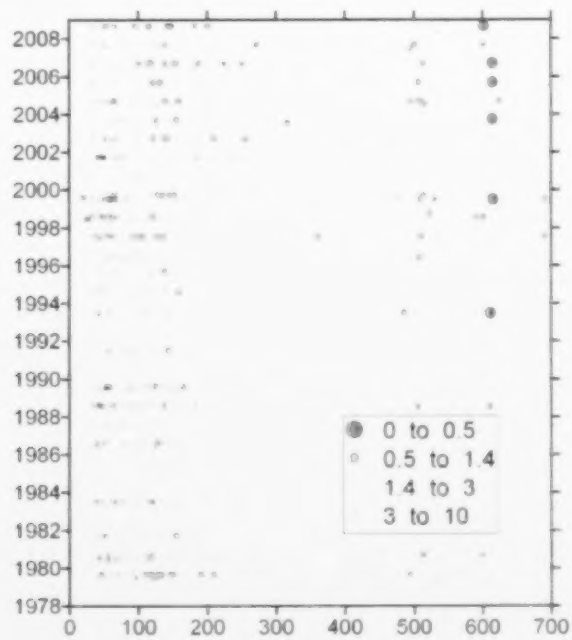


Figure 4. Oxygen concentrations (ml/litre) measured in the bottom 20 metres off the west and north coasts of Vancouver Island. Lower axis presents the depth of bottom at the measurements site.

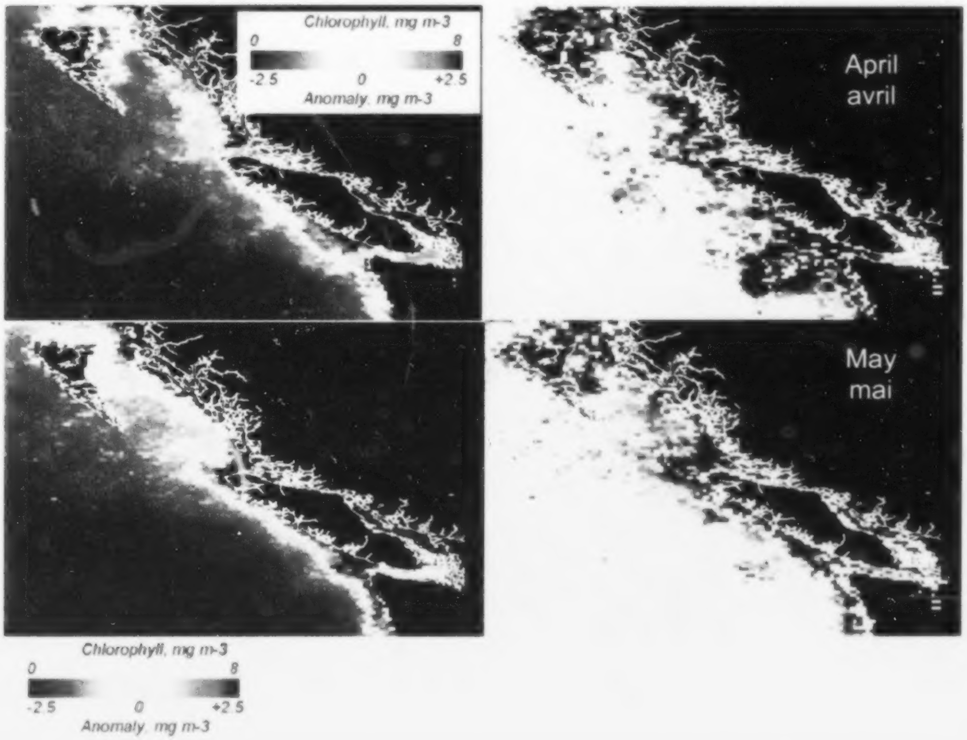
Chlorophyll anomalies observed by satellite

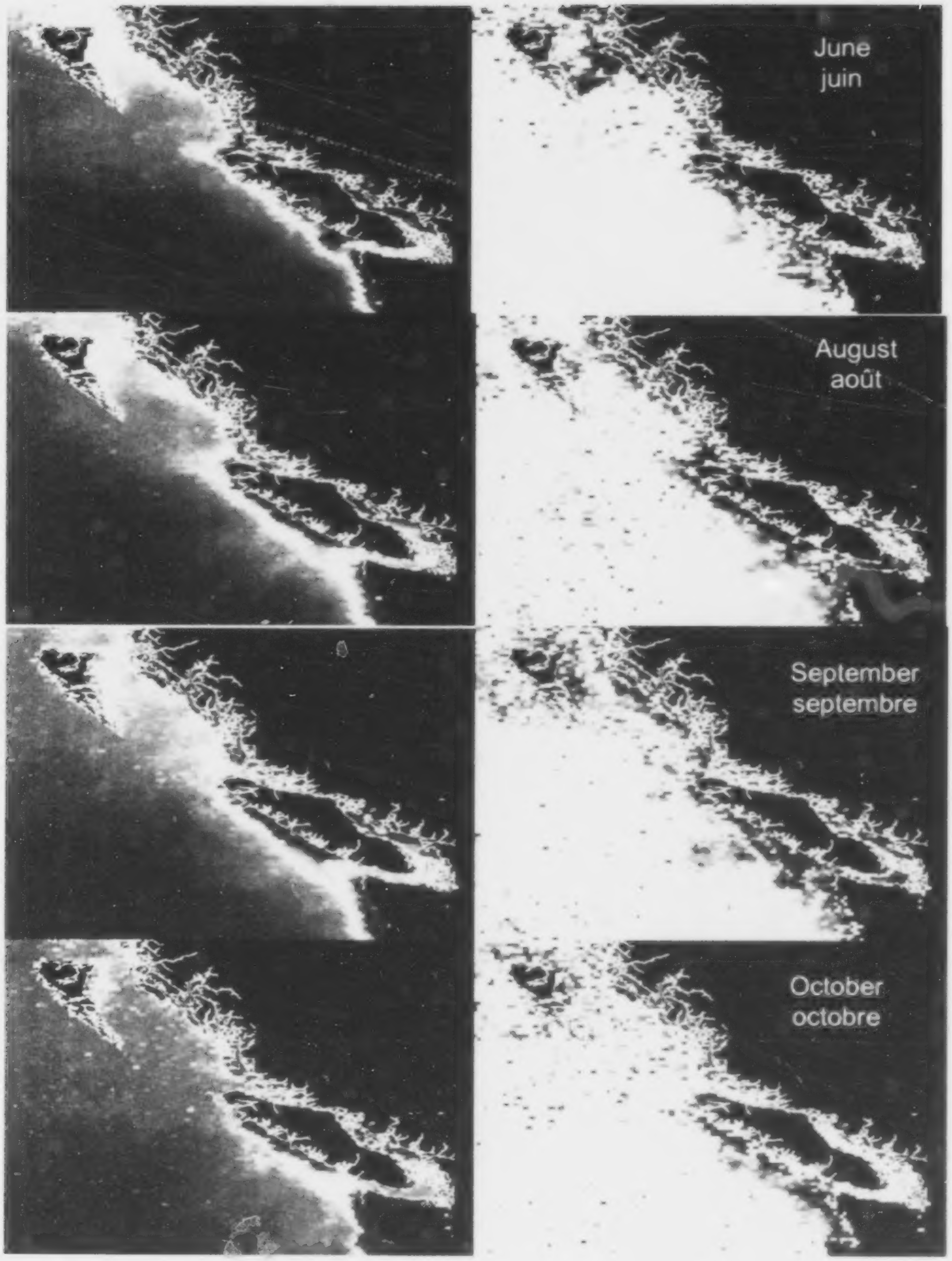
Leslie Brown and Gary Borstad, ASL Borstad Remote Sensing Inc.

The SeaWiFS satellite now has a decade of observations of chlorophyll in the ocean, enough to provide useful images of monthly climatology of chlorophyll in each month (below left) and anomalies of chlorophyll in individual months in 2008 (below right). These images provide useful information on the concentrations of phytoplankton at the ocean surface, since almost all oceanic chlorophyll resides in phytoplankton. Note that due to SeaWiFS sensor problems there are no anomaly data available for January, February, March or July 2008, and the August 2008 anomaly represents the period August 19-31 only. Low sun angle and clouds obscured most observations in November and December.

In April and May, phytoplankton were present in relatively high concentrations near Vancouver Island. Studies of seabirds off the northwest point of Vancouver Island indicate that high phytoplankton concentrations near there in April are needed for successful rearing of seabird chicks. These chicks reared very successfully in 2008, as expected from the chlorophyll anomalies. Higher-than-average concentrations off the west coast of Vancouver Island continued through June. Strait of Georgia phytoplankton were also in very high concentrations.

Figure 1. Presented below are monthly chlorophyll climatology (left) and 2008 anomaly (right) images, for months with valid SeaWiFS data. Concentrations and anomalies are represented by colours according to the colour bar below. In the anomaly images, red and yellow shading denote more chlorophyll (and therefore higher concentrations of phytoplankton) than the 10-year average for the month. Light blue and dark blue denote fewer phytoplankton. Green denotes average phytoplankton concentrations. Black indicates land. White denotes regions obscured by clouds.





Phytoplankton anomalies were very high in deep-sea waters of the Gulf of Alaska in August and September, as noted in other reports, but lower than usual along the west coast of Vancouver Island in August to October. Anomalies were also very high in September along the north and west coasts of the Queen Charlotte Islands, and along eastern Hecate Strait.

Zooplankton community returns to 'cool-ocean' pattern off Vancouver Island

David Mackas, Moira Galbraith, and Deborah Faust, Fisheries & Oceans Canada

Zooplankton time series coverage of the Vancouver Island continental margin extends from 1979 to present for southern Vancouver Island, and from 1990 to present (but with low sampling intensity and taxonomic resolution 1991-1995) for northern Vancouver Island. The grid of standard sampling locations is shown in Figure 1; additional locations are included in within-time-period averages when they are available. Sampling consists of vertical net hauls with black bongo nets (0.25 m^2 mouth area, 0.23 mm mesh aperture) from near-bottom to sea surface on the continental shelf and upper slope, and from 250 m to surface at deeper locations. Mackas, Thomson & Galbraith (2001) provide more detailed descriptions of sampling and data analysis methods.

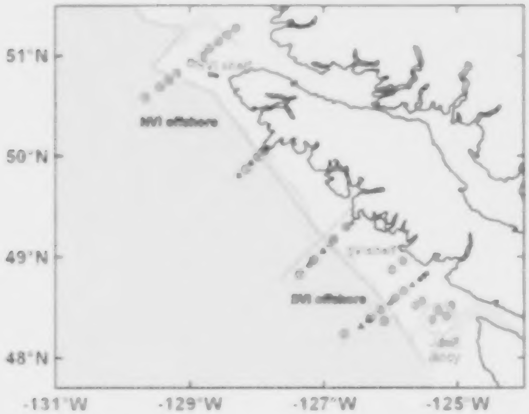


Fig 1 Standard zooplankton sampling stations off the Vancouver Island continental margin (circles), and their spatial classification into statistical areas. Triangles show supplementary CTD stations.

We routinely estimate abundance and biomass for more than 50 zooplankton taxa. Seasonal variability is intense and somewhat repeatable from year-to-year. Figure 2 shows average seasonal cycles (1979-2005) for two of the southern Vancouver Island sub-regions.

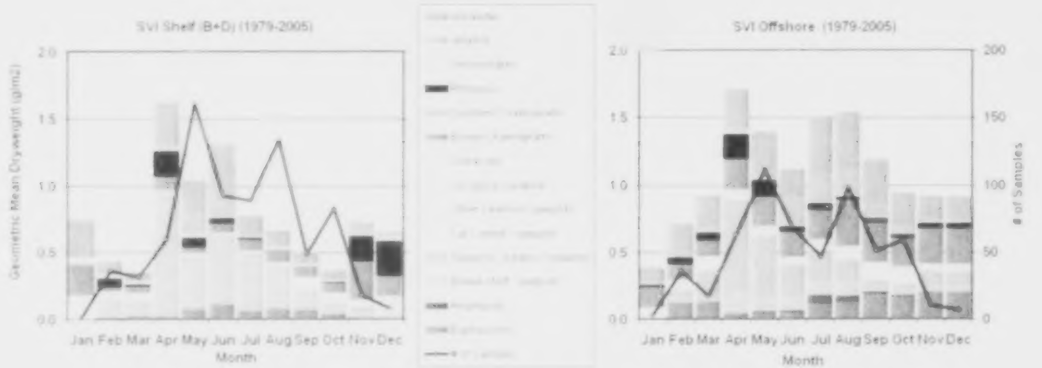


Fig 2. Average seasonal cycles (geometric mean of dryweight biomass) for the Southern Vancouver Island Shelf and Offshore regions shown in Fig. 1. Columns show cumulative amount within 14 summary taxonomic groups. Black lines show the number of samples included in each monthly and regional average.

We describe year-to-year differences in amount and species composition by calculating time series of annual anomalies (deviations from the local average seasonal cycles shown in Fig 2). The zooplankton anomalies are logarithmic: an annual anomaly of +1 means that the zooplankton were on average ten times more common than their seasonal norm; an anomaly of −1 means they were one tenth as common. To summarize these results, we further average the anomalies within groups of species sharing similar ecological niches and zoogeographic ranges. Before 2007, our reports of zooplankton anomalies (Mackas, Thomson & Galbraith, 2001; Mackas, Batten & Trudel 2007; early State of the Ocean reports) were referenced to 1979-1991 baseline averages for Southern Vancouver Island (SVI), and to a 1990-2001 baseline for Northern Vancouver Island (NVI). Since 2007 (including this report), our anomaly time series have been recalculated using a longer (to 2005) reference baseline. The main effect is that we now include the warm years of the 1990s and 2004-2005 in the long term averages for Southern Vancouver Island. This shifts the SVI anomaly time series vertically, so that the complete time series are now centred around a zero mean (see comparisons of 'old' and 'new' anomaly time series in Fig. 3). Fig. 3 (Southern Vancouver Island) and Fig. 4 (Northern Vancouver Island) show the cross-shore and annually averaged biomass anomalies for several important zooplankton species groups.

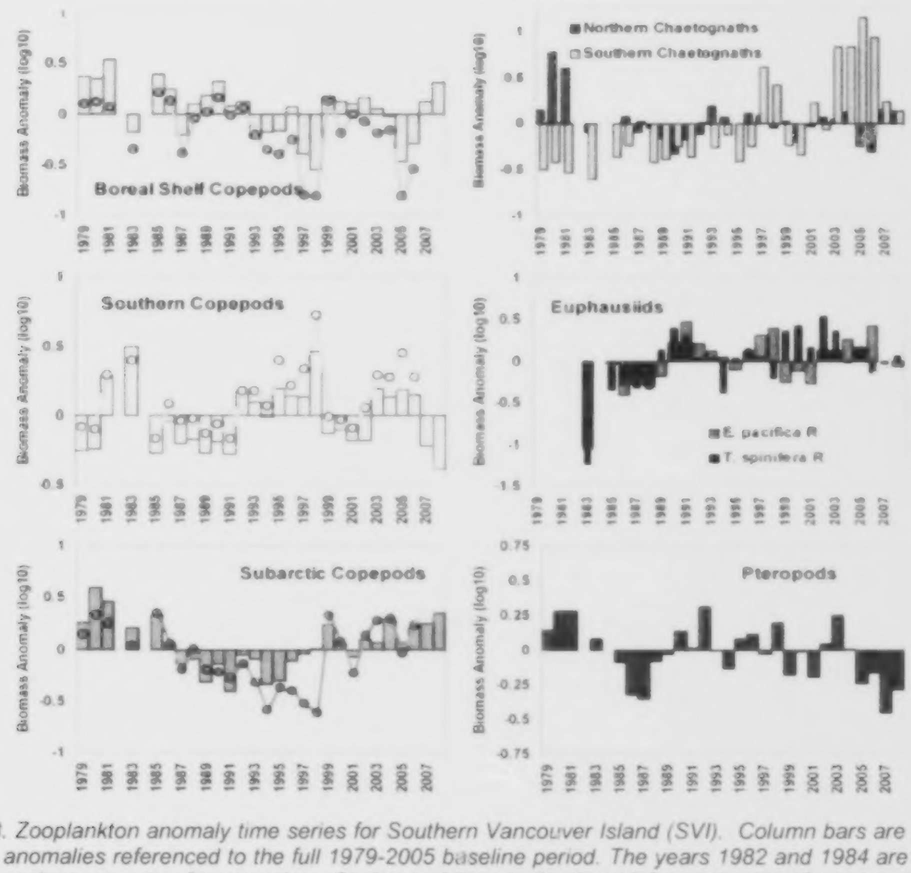


Fig. 3. Zooplankton anomaly time series for Southern Vancouver Island (SVI). Column bars are species group anomalies referenced to the full 1979-2005 baseline period. The years 1982 and 1984 are omitted because there were too few samples. Circles and lines in the three left panels show for comparison the older anomalies (1979-1991 baseline). Euphausiid anomalies are reported only since 1983 (after a change in sampling method) and have been corrected for day vs. night effects on capture efficiency

Sequences of anomalously warm years were frequent during the past two decades. Warm ocean temperatures have direct effects on biota, but are also correlated with other important environmental factors such as strong vertical density stratification, resistance to wind-mixing and upwelling, reduced nutrient supply, reduced plankton productivity, and poleward anomalies of transport and migration. All of these push the zooplankton community toward reduced growth and survival of resident species, and increased abundance of their 'warm-water' competitors and predators. These shifts in community composition are very evident in the SVI zooplankton anomaly time series (Fig. 3). During the 1990s warming trend, we saw a strong and progressive shift to a more 'southerly' copepod fauna, and reduced abundance of the endemic 'boreal shelf' copepods. The zooplankton trends reversed very sharply in 1999, following the 1999 La Niña event. From 1999-2002 (cool in the NE Pacific) zooplankton biomass and community composition along the Vancouver Island continental margin was similar to the late 1980s. Warm conditions resumed 2003-2005, and zooplankton responded ('southern' origin copepod species significantly more abundant than average, resident 'northern' copepods much less abundant than average).

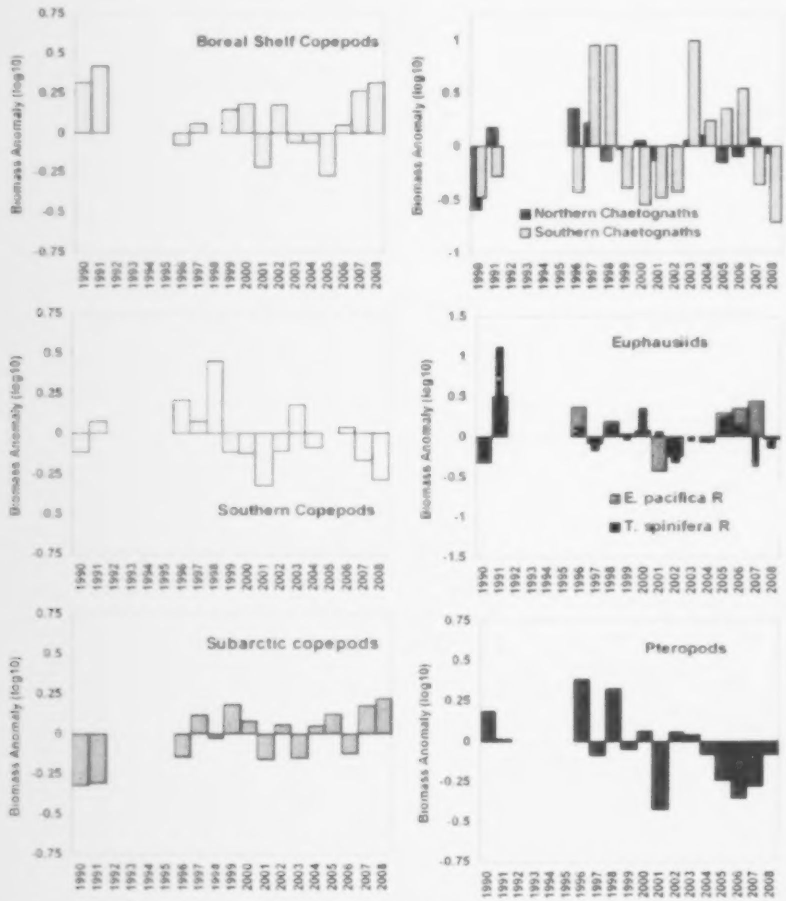


Fig. 4. Zooplankton anomaly time series for Northern Vancouver Island (NVI). The years 1992-1995 are omitted from the plots because there were too few samples to give reliable anomaly estimates.

Poleward/equatorward displacements were seen in other zooplankton groups, especially the chaetognaths. Cooler ocean conditions began to return in early 2006, but recovery of the boreal shelf copepods and northern chaetognaths and decline of the southern copepods and chaetognaths were delayed and more gradual. In 2007, the 'cool ocean' community mix was confined primarily to the continental shelf. But in 2008, positive anomalies of cool-water (and negative anomalies of warm-water) zooplankton species groups were strong in all regions, leading to a zooplankton community similar in amount and composition to the beginning of our time series.

The briefer Northern Vancouver Island region anomaly time series (Fig 4) are qualitatively similar to SVI (bad for endemic species and good for southern species during warm years), but anomaly amplitudes off NVI are in general smaller. Zooplankton anomaly time series from further south in the California Current system also show similar patterns of interannual-to-decadal variability (Mackas, Peterson, Ohman & Lavaniegos, 2006).

Biomass of the 'subarctic oceanic' copepods (*Neocalanus spp.*) have been gradually increasing in NVI and SVI offshore regions since 1990. These large copepods make up most of the zooplankton biomass in the Alaska Gyre, and have an annual life cycle that includes a brief growing season from spring into early summer followed by departure from the surface layer for a prolonged dormancy much deeper in the water column (between 400-1500 m). The annual biomass maximum, and maximum availability as food for upper ocean predators, is therefore brief (about 3-4 weeks) and occurs just before the start of this dormant period. We have observed a very strong association between seasonal timing and ocean temperature (Mackas et al. 1998, 2007; see also Batten this report), with the annual biomass peak and onset of dormancy occurring early in the year if the upper ocean is warm in spring, and late if the water is cool. The years 2003-2006 were among the earliest recorded, both along the Vancouver Island continental margin, and in the Alaska Gyre. Timing in 2007 was near the long-term average in both regions. Timing in 2008 was later than average (late June-early July) in the Alaska Gyre and near-average (mid-late May) along the continental margin.

The changes in zooplankton community composition in the past 2 decades appear to have had large effects on fish growth and survival (Mackas Batten & Trudel 2007; Trudel this report), probably because the 'cool water' zooplankton are better fish food (larger individual body size and much higher energy content). Because much of the year-to-year variability of marine survival rate of harvested fish species occurs at early life stages (for salmon, in their first year after ocean entry), recent zooplankton anomalies provide a useful index of juvenile fish nutrition and a 'leading indicator' for subsequent adult fish recruitment. In pursuit of this goal, Mackas, Batten and Trudel, 2007 (results summarized in PSARC FOWG 06 and 07 reports) used multivariate ordination of the covariance among zooplankton composition and timing anomalies, local and large-scale indices of upper ocean temperature, and 'success' of predator species (growth and marine survival of outer coast coho; sablefish recruitment; seabird reproductive success). We found that interannual variability of all of these time series projected strongly onto a single component axis (loosely interpretable as a 'cool-and-productive' to 'warm-and-unproductive' gradient). In Fig 5, we apply our original variable-weighting coefficients to our extended and updated data records to produce an extended time series of scores for this principle component. The years 1983, 1992-1998, and 2003-2006 all score as "warm and unproductive". However, our data suggest that predator reproductive success and early marine % survival of salmon may have been much better in 2008.

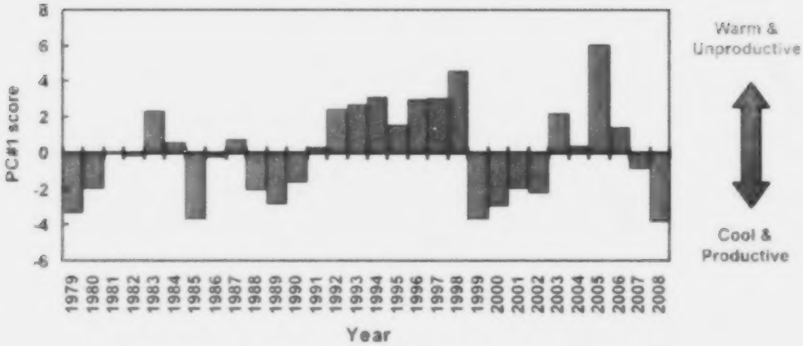


Figure 5. Annual scores for zooplankton-temperature-predator PC#1. Blue indicates cool temperature and favourable conditions for most of the endemic zooplankton and predators, red indicates warm and favourable for the southern zooplankton but unfavourable for endemic zooplankton and predators.

References

Mackas, D.L., S. Batten, and M. Trudel. 2007. Effects on zooplankton of a warming ocean: recent evidence from the North Pacific. Progr. Oceanogr. 75: 223-252.

Mackas, D. L., W. T. Peterson, M. D. Ohman, and B. E. Lavaniegos 2006, Zooplankton anomalies in the California Current system before and during the warm ocean conditions of 2005, Geophys. Res Lett., 33, L22S07, doi:10.1029/2006GL027930.

Mackas, D.L., R. Goldblatt and A.J. Lewis. 1998. Interdecadal variation in developmental timing of Neocalanus plumchrus populations at Ocean Station P in the subarctic North Pacific. Can. J. Fish. Aquat. Sci. 55:1878-1893.

Mackas, D.L., R.E. Thomson and M. Galbraith. 2001. Changes in the zooplankton community of the British Columbia continental margin, and covariation with oceanographic conditions, 1985-1998. Can. J. Fish. Aquat. Sci. 58: 685-702.

Euphausiids and hake: Less food for coho and herring, and declining hake

Ron Tanasichuk, Fisheries & Oceans Canada

One of our research activities focuses on evaluating simultaneously the influences of egg deposition levels, food, competition, and predation on the productivity of Pacific herring (*Clupea pallasi*), and coho (*Oncorhynchus kisutch*), sockeye (*O. nerka*), and hatchery chum (*O. keta*) salmon along the south-west coast of Vancouver Island (WCVI). Our diet analysis indicates that herring and salmon select the euphausiid (krill) *Thysanoessa spinifera* over other potential prey species. Herring and coho consume prey longer than about 17 and 19 mm respectively. Most krill fed upon by sockeye were 3-5 mm while those consumed by chum were 3-4 mm.

The 1991-2008 time series of *T. spinifera* biomass (Fig. 1) indicates increased, but still low, levels in 2008. Pacific hake (*Merluccius productus*) dominates the pelagic biomass in summer and is potentially the most important predator on young herring and salmon. Hake can also be a competitor because *T. spinifera* is also a key prey item for them.

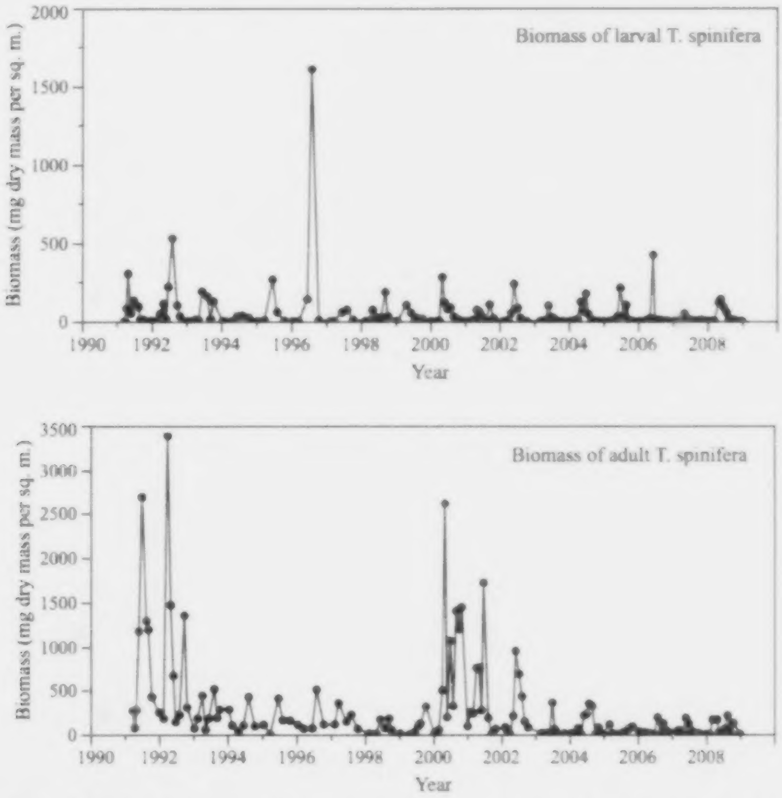


Figure 1 The 1991-2008 time series of larval (top panel, <10 mm long) and adult (bottom panel > 9 mm long) T. spinifera biomass. Median larval and adult biomasses in 2008 were at the average and the fifth lowest respectively in the time series; larval biomass increased by 300% and adult biomass increased by 169% from 2007.

The 1999 hake year-class was quite strong. In 2004, hake from this year-class became large enough to start consuming fish. Preliminary results from the 2007 Joint Canada-US hake coast-wide hydroacoustic survey indicate that hake biomass is declining because of gradual disappearance of the 1999 year-class and no strong subsequent recruitments.

Evidence suggests that herring recruitment (production of new spawners) varies as a result of egg deposition, *T. spinifera* biomass and/or hake biomass effects. Interestingly, WCVI euphausiid biomass appear to be a useful predictor for major herring stocks in other areas. Recruitment variation for northern BC (Queen Charlotte Islands, North Coast, Central Coast) herring results from the effects of egg deposition, *T. spinifera* biomass, and/or interactions with hake during herring's second year of life. For Strait of Georgia herring, recruitment varies in response to egg deposition and hake predation when, as young-of-the-year, these herring move to offshore feeding areas along the WCVI. Recruitment variability for WCVI herring is caused by variations in *T. spinifera* biomass and competition with hake when herring are in their first year of life. *T. spinifera* biomass variability also helps explain changes in growth of WCVI herring, and variation in adult natural mortality rates for WCVI, Strait of Georgia, Central Coast, and North Coast herring. WCVI euphausiid biomass also appears to be a useful predictor for some salmon stocks. For instance, WCVI wild coho return variability is affected by *T. spinifera* biomass variability early in marine life. Much of the Barkley Sound (Sproat and Great Central lakes) and Central Coast (Long Lake) sockeye return variability can be explained by variations in *T. spinifera* biomass early in marine life. Nitinat hatchery chum productivity, as indexed by returns of ages 4 and 5 fish, is affected mostly by variations in hake biomass, but *T. spinifera* biomass early in marine life also affects the return of age 3 chum.

The status of *T. spinifera* prey biomass in 2008 for a given predator may not be reflected in the trend for larval or adult biomass. This is a consequence of: 1) each predator selecting a specific size range of the *T. spinifera* biomass, and 2) a possible mismatch between the seasonality of *T. spinifera* production and the critical period within which a given predator depends on energy from *T. spinifera*.

I believe that the following are the anticipated consequences of 2008 prey and predator biomass levels;

- Herring: recruitment to all major BC stocks will increase in 2009 because of a reduction in hake biomass as of 2006 (this may be tempered somewhat by low *T. spinifera* prey biomass for WCVI herring); low *T. spinifera* prey biomass in 2008 will result in poor growth of WCVI herring and higher adult natural mortality rates for WCVI, Strait of Georgia, Central Coast, and North Coast populations;
- WCVI wild coho: marine survival is forecast to remain relatively low, about 6%, for the 2009 return year because of reduced *T. spinifera* prey biomass in the 2008 smolt year;
- Barkley Sound/Central Coast sockeye: returns in 2009 will increase from 2008 because of higher *T. spinifera* prey biomass in the 2007 and 2008 smolt years;
- Nitinat River Hatchery chum: return should increase in 2009 from 2008 because of a reduction in hake predation that began in 2006.

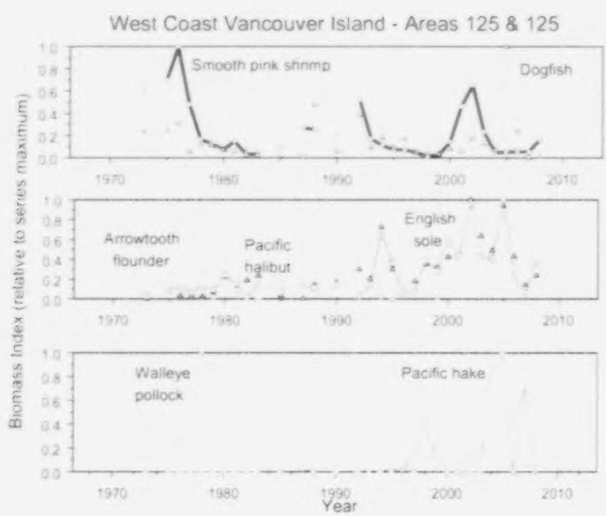
Small-mesh bottom-trawl surveys: Increased biomass of smooth pink shrimp

Ian Perry, Jim Boutillier, Dennis Rutherford. Fisheries & Oceans Canada

Bottom-trawl surveys using a small-mesh net (targeting the smooth pink shrimp *Pandalus jordani*) have been conducted during May since 1973. The survey in 2008 found the biomass of *Pandalus jordani* shrimp off central Vancouver Island had increased from very low levels during 2004-2007, possibly as a result of colder ocean conditions when they were hatched in 2006; this population may be beginning to recover after warm conditions during mid-decade. Biomass of flatfish species also increased in 2008 after declines in 2006 and 2007. Some biomass changes, such as for spiny dogfish, English sole and Pacific hake in recent years, may be due to increased catches of adult fish rather than sub-adults. Time series of pelagic, demersal and benthic taxa suggest biomasses tended to be low from mid-1970s to mid-1980s and high in the early 2000s. In 2008, more taxa had biomasses in their mid to high range than in their lowest range.

Figure 1. (left). Map showing the three main shrimp (Pandalus jordani) survey grounds off Vancouver Island (red ovals). The Nootka (Area 125) and Tofino (Area 124) Grounds are the northern and middle ovals, respectively.

Figure 2. (below): Time series of normalised (to maximum biomass) survey catches of smooth pink shrimp, dogfish, Pacific halibut, Arrowtooth flounder, English sole, Pacific hake and walleye pollock.



Small Pelagic Fishes

Jake Schweigert, Fisheries & Oceans Canada

West Coast of Vancouver Island

Herring abundance off the west coast of Vancouver Island decreased from 1977 through to the present to levels not seen since the late 1960s. Abundance in 2008 was similar to 2006 and 2007 and remained well below the fishery threshold. Previous warm ocean temperatures in 2003 to 2006 appear to be associated with poor recruitment for herring (the opposite of herring stocks in the Strait of Georgia), and an increase in summer biomass of predators. This trend might reverse with recent cooling.

Sardine returned to southern Vancouver Island waters in 1992 after a 45 year absence, and expanded their distribution northward throughout the west coast of Vancouver Island, Hecate Strait and Dixon Entrance by 1998. Sardine spawning was reported off the west coast of Vancouver Island in 1997 and 1998. In 2008 sardines appeared in Canadian waters in late June. The distribution was similar to that in 2006 and 2007 and concentrated north of Vancouver Island in southern Hecate Strait and Queen Charlotte Sound. The exceptionally strong 2003 year-class continues to be an important factor in the widespread distribution of large sardines throughout the area.

North Coast

Exploitable herring biomass in the north coast area is an amalgamation of migratory stocks from the Queen Charlotte Islands, Prince Rupert and Central Coast areas. Recruitment in the Queen Charlotte Islands stock has been reduced for the past decade, resulting in low abundance, while recruitment in the Prince Rupert and Central Coast stocks has been generally good, because of sporadic strong year classes. However, two of the most recent year-classes (2003 and 2005) have been weak in these areas resulting in further decline in abundance from the previous year. The recent trend towards cooling ocean conditions is anticipated to result in improved herring recruitment in this region over the next few years.

Strait of Georgia

Herring survival conditions and recruitment have been unusually good in the Strait of Georgia for the last decade. Abundance of herring reached near historical high levels from 2002-2004 exceeding 100,000 mt. However, the 2003 and 2005 year-classes are relatively weaker resulting in a substantial decline in abundance in recent years. Nevertheless, the stock remains at a healthy level in the short term.

Small pelagic fishes: detailed analyses

<u>Herring off the west coast of Vancouver Island</u>

Since about 1977, the recruitment of herring off the west coast of Vancouver Island has been generally poor interspersed with a few good year-classes (Figure 1). As a result, the productivity of the west coast of Vancouver Island herring stock has been declining since the early 1980s (Figure 1). Research studies have shown that herring recruitment in this region tends to be negatively correlated with temperature probably reflecting: 1) poor feeding conditions for herring larvae and juveniles during their first growing season; and 2) a general increase in the mortality rate of the larvae and juveniles, due to an increase in the intensity of invertebrate and fish predation in the rearing area in warm years. Studies to measure the predation rate confirm that the negative correlation between herring recruitment and hake biomass could be caused by

predation or competition for food. Ocean conditions were warmer in 2002 to 2006, impacting herring survival, in and resulted in reduced biomass and recruitment. However, more recent cooling ocean conditions combined with declining hake conditions should result in improved herring recruitment over the next few years.

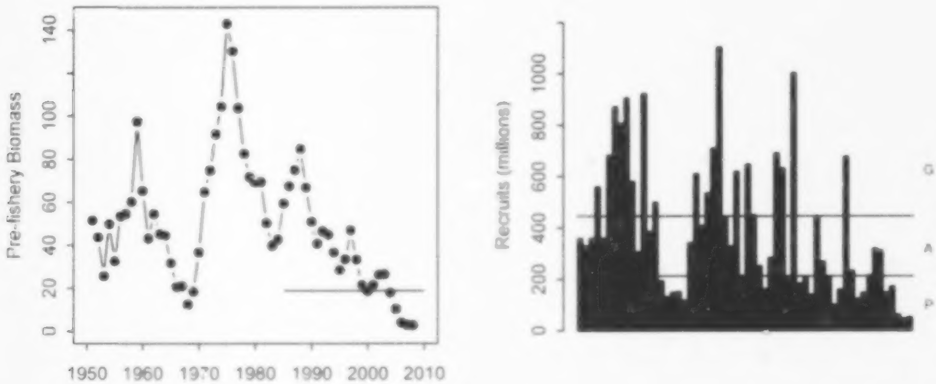


Figure 1. Interannual variability and decadal trends in abundance and recruitment to the west coast of Vancouver Island herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 5 of the last 10 recruitments have been 'poor'.

Pacific Sardine off the west coast of Vancouver Island

Pacific sardine is a migratory species and when the population is healthy and ocean conditions are favourable, sardines migrate to British Columbia in the summer to feed. Most of these summer migrants make a return spawning migration in the fall to the waters off central and southern California. The sardine fishery in Canadian waters collapsed in 1947 without warning and by the early 1950s off California due to unfavourable environmental conditions. After a 45-year absence from British Columbia waters, sardines reappeared off the west coast of Vancouver Island in 1992. From 1992-1996, their distribution was limited to the southern portion of Vancouver Island. In 1997, their distribution expanded northward and by 1998 sardines inhabited waters east of the Queen Charlotte Islands throughout Hecate Strait and up to Dixon Entrance. Spawning was reported off the west coast of Vancouver Island in 1997 and 1998. In 1999 following the El Niño, sardine distribution again contracted southward. During 2006 and 2007, sardines appeared in Canadian waters in late-June and were distributed offshore and largely north of Vancouver Island into southern Hecate Strait and Queen Charlotte Sound. A survey of salmon along the west coast of Vancouver Island in 2008, based on by-catch during the salmon survey, reveals considerable numbers in this region. (Figure 2). The most recent U.S. assessment suggests that coast-wide abundance off Canada and the lower 48 states peaked in 2000 and has declined since, decreasing to about 600,000 tonnes in 2008 (Fig. 3).

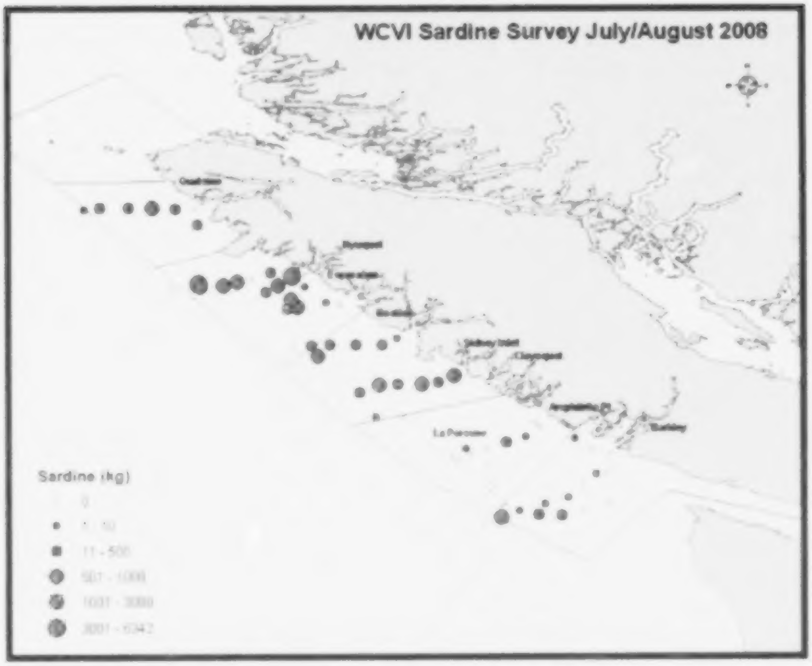


Figure 2. Distribution of Pacific sardine in BC waters during 2007 based on by-catch in the high seas salmon surveys.

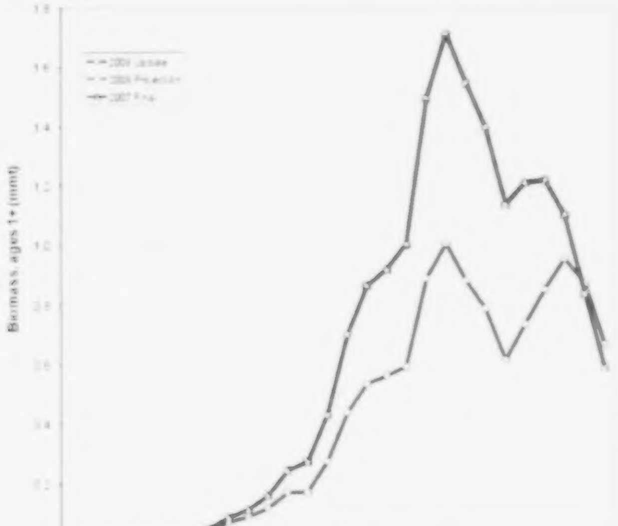


Figure 3. Time series of Pacific sardine stock biomass off Canada and USA (x1,000 mt) of age 1 and older fish, estimated from an age-structured stock assessment model (data from Hill et al. 2008).

Herring in Hecate Strait

The exploitable biomass of herring in the Hecate Strait area is an amalgamation of the three major migratory stocks in the Queen Charlotte Islands, Prince Rupert, and in the Central Coast. Over the past decade, abundance in the Queen Charlotte Islands has been depressed whereas abundance in both Prince Rupert and the Central Coast has remained at healthy levels (Figs. 4, 5, 6). Levels of recruitment to the Queen Charlotte Islands stock have been depressed (Fig. 4) with only 2 of the past 10 year-classes not being poor while the Prince Rupert stock (Fig. 5) has experienced a good recruitment at least every 4 years since 1980. Recruitment to the Central Coast stock (Fig. 6) has been less regular but the 'good' year-classes that have occurred were very strong. Indications are that the most recent recruitments (2003-2005 year-classes) are poor or average and resulted in declines all three northern stocks. Cooler conditions since 2005 combined with a declining hake population should be positive for herring recruitment in this area in the next few years.

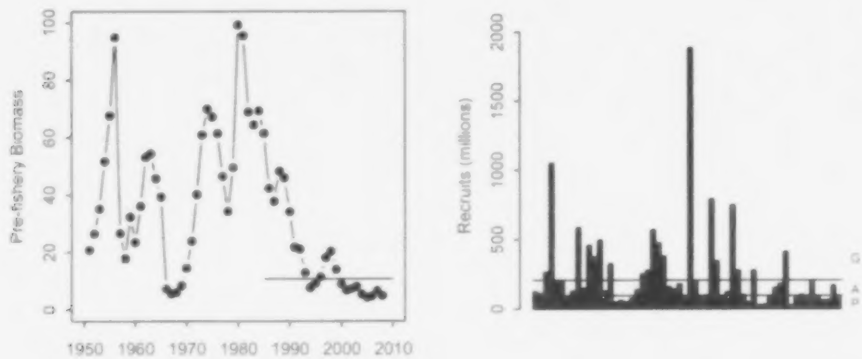


Figure 4. Interannual variability in abundance and decadal trends in recruitment to the Queen Charlotte Islands herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that only 2 of the last 10 recruitments have been 'good'.

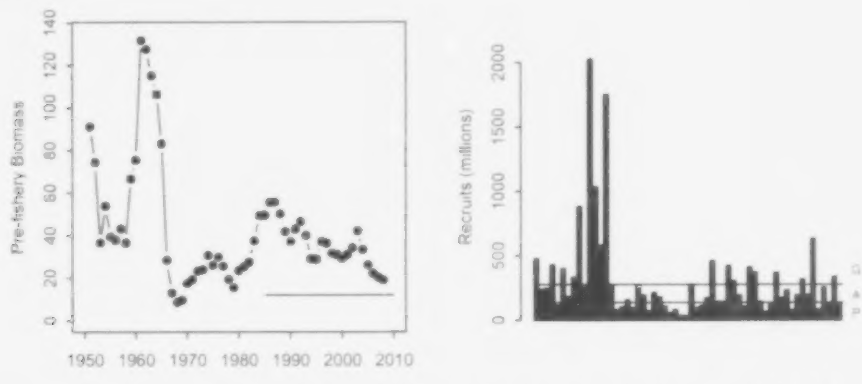


Figure 5. Interannual variability in abundance and decadal trends in recruitment to the Prince Rupert District stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 'good' recruitments have occurred almost every four years since 1980.

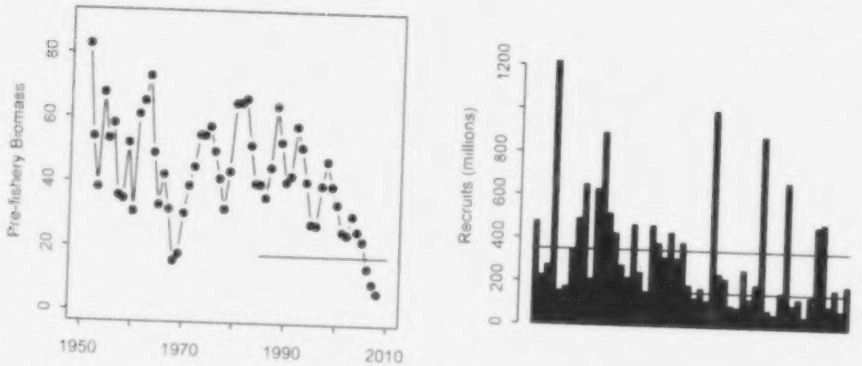


Figure 6. Interannual variability in abundance and decadal trends in recruitment to the Central Coast stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

Herring in the Strait of Georgia

The Pacific herring stock in the Strait of Georgia migrates inshore in the fall and leaves the Strait in the spring following spawning. Survival conditions for juvenile herring in the Strait of Georgia have been unusually good during the last decade. Abundance of herring in the Strait of Georgia reached near historic high levels from 2002-2004 at over 100,000 tonnes (Fig.7). Recruitment to this stock has been very strong with 9 of the last 10 year-classes being average or better (Fig. 7). The strongest recruitment occurred in 2002 and subsequent year-classes have been progressively smaller. The most recent recruitment in 2008 was poor. Juvenile rearing conditions within the Strait of Georgia appear to be an important determinant of recruitment success for this stock since most juveniles do not leave the area until their second summer. Initial indications are that the recruitment in 2009 should be better than 2008 but 2010 could also be weak based on surveys of juvenile abundance and could lead further declines in overall abundance.

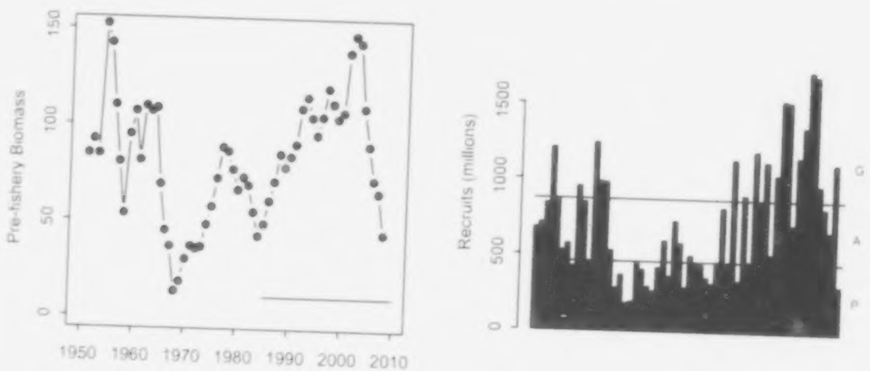


Figure 7. Interannual variability in abundance and decadal trends in recruitment to the Strait of Georgia stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

Small Pelagic Fishery Interpretation and Speculative Results

West Coast Vancouver Island

Herring: Herring on the west coast of Vancouver Island is at an historically low level and will remain so unless ocean conditions resulting in a reduction in the abundance of predators in the area improve. Recent conditions have not been favourable for herring survival in 2005 although 2006 should be better, and given reductions in hake abundance we can anticipate improved recruitment in the next few years.

Sardine: Sardines reappeared off the west coast of Vancouver Island in 1992. During the 1990s their distribution expanded northward from southern Vancouver Island through Hecate Strait to Dixon Entrance. In 2003 and 2004 the distribution of sardines in B.C. limited to the inlets of Vancouver Island and offshore areas in the south. Warm conditions in 2002 to 2006 and a very strong 2003 year-class has resulted in widespread distribution of sardines throughout southern Hecate Strait and Queen Charlotte Sound in 2006 through 2008.

North Coast Major

Herring: Herring in the Hecate Strait area consist of migratory stocks from the Queen Charlotte Islands, Prince Rupert and Central coast areas. For the past decade, recruitment and abundance of the Queen Charlotte Islands stock has been low while recruitment and abundance of the Prince Rupert and Central Coast stocks have been generally good. Recruitment of the 2003 and 2005 year-classes was weak in all three areas resulting in slight declines in all three areas in 2008. Cooling conditions in the past few years combined with declining hake abundance should result in improved herring recruitment in this area in the short term.

Strait of Georgia

Herring: The abundance of herring in 2008 continued the decline that began in 2002 from the near historic high levels of more than 100,000 tonnes. The declining trend in recruitment over the past five years will translate into reduced mature abundance levels over the next few years. Fall surveys of juvenile herring suggest an average recruitment in 2009 followed by a weaker year-class in 2010.

Eulachon declines in the Fraser and along west coast Vancouver Island

Jake Schweigert, Fisheries and Oceans Canada

Eulachon (Thaleichthys pacificus) belong to the Family Osmeridae (smelts) and are distributed from northern California to the southern Bering Sea, although populations south of the Columbia River appear to be extirpated. Inhabiting predominately spring freshet rivers, most eulachon spawning occurs during March and April when the fish are age-3 but two of the largest eulachon runs occur either earlier (January for the Columbia River) or later (into May for the Fraser River) (Hay et al. 2002). Diminished eulachon returns coastwide during the 1990s raised concerns about the status of stocks in both the United States and Canada and the possibility for continued fishing opportunities for this species. Based on these conservation concerns, fishing restrictions were implemented both in BC and Washington State. An egg and larval survey was initiated in 1995 to estimate spawning stock biomass on the Fraser River for stock assessment purposes. In the same year, an in-season test fishery program was initiated to provide information on the number of eulachon returning to spawn in the Fraser River. Reasonably abundant early catches from these surveys were used as a basis to open fisheries in some years. Two additional indicators have been used to make recommendations concerning Fraser River eulachon. These include the offshore biomass index derived from the annual shrimp trawl survey conducted on the west coast of Vancouver Island since 1973 and the Columbia River catch data.

An egg and larval survey has been conducted on the Fraser River since 1995 and appears to provide the best estimator of eulachon spawning biomass (Figure 3). Despite limited directed fisheries in recent years, the Fraser River eulachon stock remains at a precariously low level (Figure 4). This stock has failed to recover from its collapse. SSB estimated from the egg and larval survey conducted in 2008 was 10 tonnes.

Figure 3. Sampling stations on the lower Fraser River. DI – Dease Island, NA – North Arm, NW – New Westminster.

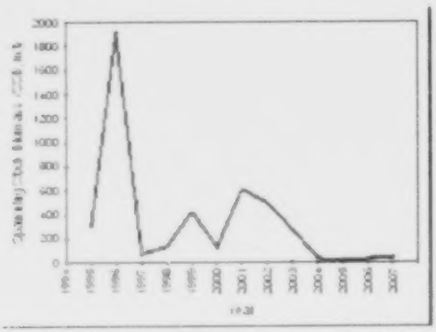


Figure 4. Spawning stock biomass (SSB) estimated by the egg and larval survey on the Fraser River, 1995-2007.

An offshore eulachon biomass index has been calculated annually for both Shrimp Management Areas (SMAs) 124Off and 125Off based on incidental catches in the shrimp research survey (Figure 5). This index has been highly variable between 1973 and 2007 for both areas (Figure 6). In some years changes in biomass are mirrored between areas 124Off and 125Off while in others they are not. Although the biomass in areas 124Off and 125Off was very low in 2004

and 2005, this index was lower in the mid- to late-1990s. In 2007, the index remained low and is at comparable levels to the mid- to late-1990s. The biomass index for 124Off was 206 tonnes while for 125Off it was 52 tonnes.

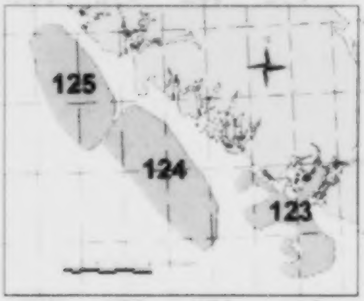


Figure 5. Location of offshore Shrimp Management Areas 124Off and 125Off. 123Off is included for reference

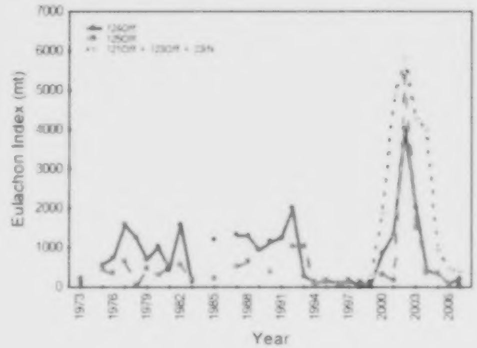


Figure 6. Offshore eulachon index for Shrimp Management Areas 124Off, 125Off and 121Off/123Off/23In combined, 1973-2007.

Previously, Hay et al. (2003) and Hay et al. (2005) have suggested that a "poor" fishery in the Columbia River would have reported catches of less than 500 tonnes, a situation that has occurred since 1993 when eulachon stocks collapsed in many BC and US rivers. Commercial eulachon landings from the Columbia River in 2007 were 3.8 tonnes (Figure 7).

Although not a pre-season indicator, the Fraser River test fishery has provided a post-season perspective on run size (Figure 8). A test fishery for eulachon on the Fraser River was not been conducted since 2005.

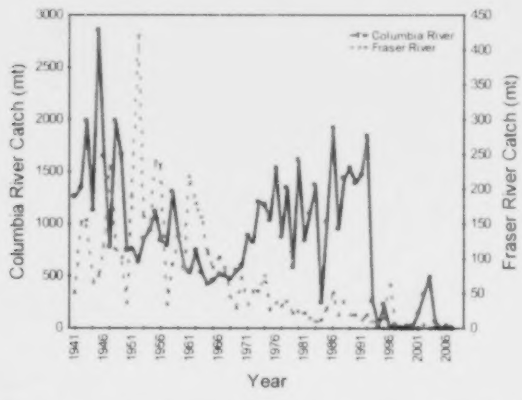


Figure 7. Commercial eulachon catches from the Columbia River (left axis) and Fraser River (right axis) from 1941-present.

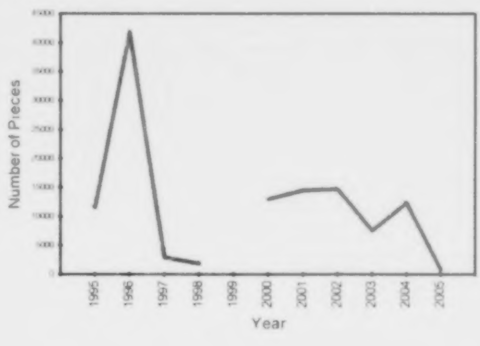


Figure 8. Fraser River eulachon test fishery, 1995-2005.

References

Hay DE, McCarter PB, Joy R, Thompson M, West K (2002) Fraser River eulachon biomass assessments and spawning distribution: 1995-2002. Canadian Science Advisory Secretariat Research Document 2002/117: 57pp.

Hay DE, West KC, Anderson AD (2003) Indicators and 'response' points for management of Fraser River eulachon: a comparison and discussion with recommendations. Canadian Science Advisory Secretariat Research Document 2003/051: 44pp.

Hay DE, West K, Anderson AD, Rutherford D (2005) Indicators and "response" points for management of Fraser River eulachon: protocols for managing a data-limited fishery. Fisheries Assessment and Management in Data-Limited Situations, Alaska Sea Grant College Program. AK-SG-05-02: 25pp.

Sockeye Salmon Indicator Stocks –Regional Overview of Trends and 2008 Returns

Kim Hyatt, Margot Stockwell, and Paul Rankin, Fisheries & Oceans Canada

Results from recent studies (Mueter et al. 2002a, 2002b, Pyper et al. 2005) suggest that associations between Pacific salmon survival and near coastal environmental variables (upwelling index, sea surface temperature [SST], and sea surface salinity [SSS]) are strongest at local spatial scales (distances of less than 500-800 km) for adjacent stocks and exhibit little to no co-variation at spatial scales larger than 1000 km. Among three variables examined (upwelling, SST and SSS), correlation scales for SST in summer most closely matched the correlation scales for salmon survival. Furthermore, regional averages of SST appeared to be better predictors of survival rates than large-scale measures of SST variability such as the Pacific Decadal Oscillation (PDO; Mueter et al. 2002b). This suggests regional-scale variations in SST along the coast are related to the processes causing the observed co-variation in survival rates of neighbouring salmon stocks. Thus, neighbouring stocks are likely to exhibit stronger similarities in survival and production variations than stocks separated by larger distances. In addition, species comparisons suggested geographical overlap of salmon species during freshwater and early marine life stages are more important in determining shared environmental effects on survival rates (and ultimately on stock productivity) than are species differences (Pyper et al. 2005).

Comparisons of forecasts and observed returns of sockeye salmon returning to major rivers and fisheries throughout coastal British Columbia have been completed annually by DFO stock assessment personnel for decades (Figure 1). Given the observations noted above, production trends for major sockeye populations or stock aggregates (i.e. "indicator stocks") may reflect environmental changes and anticipate production trends for several salmon species originating from areas of the coast constituting separate production domains. Comparisons of trends for several sockeye indicator-stocks permit the following generalizations:

- Annual variability in total returns for all stocks is large with maximum annual returns ranging between 10 to 90 times the minimum return.
- Since 1970, maximum returns for all stocks occurred during the early 1990's immediately following the strong La Niña event of 1989.
- Central Coast, Vancouver Island (WCVI), and Fraser indicator-stocks all declined from early-1990s highs to persistent, sub-average returns since the mid-1990s (Figure 1).
- North Coast and Transboundary indicator-stocks declined from early-1990s highs, exhibited by all sockeye indicator-stocks, but relative to more southerly stocks, have remained closer to their all-year average return values since the late 1990s.
- Indicator-stocks entering continental shelf areas under stronger oceanic influences (i.e. areas 3 and 4 of Figure 1) appear more responsive to alternations in La Niña-like (anomalously cool, survival favourable) and El Niño-like (anomalously warm, survival less favourable) conditions (see detailed analysis for WCVI and Central Coast areas below) than stocks entering more protected estuarine waters (i.e. areas 1, 2, and 5 of Figure 1).
- All sockeye indicator stocks throughout the BC coast exhibited sub-average returns in 2008.
- Expectations for sub-average returns of North Coast (Nass), Central Coast (Long Lake), and WCVI (Barkley Sound) in 2008 were consistent with pre-season forecasts. By contrast, Transboundary (Tahltan) and Georgia Basin (Fraser-Chilko) indicator-stock returns were significantly lower than pre-season forecasts (i.e. areas 1 and 5 in Figure 1).
- Although there is some evidence of a return to near-average marine survival rates for 2006 sea-entry year smolts (returning as 4-year-old adults in 2008), uniformly sub-average

returns in 2008 continue to reflect a legacy of reduced returns and depressed spawner abundance associated with anomalously low smolt-to-adult survival during sea-entry years 2003-2005 (DFO 2006, 2007).

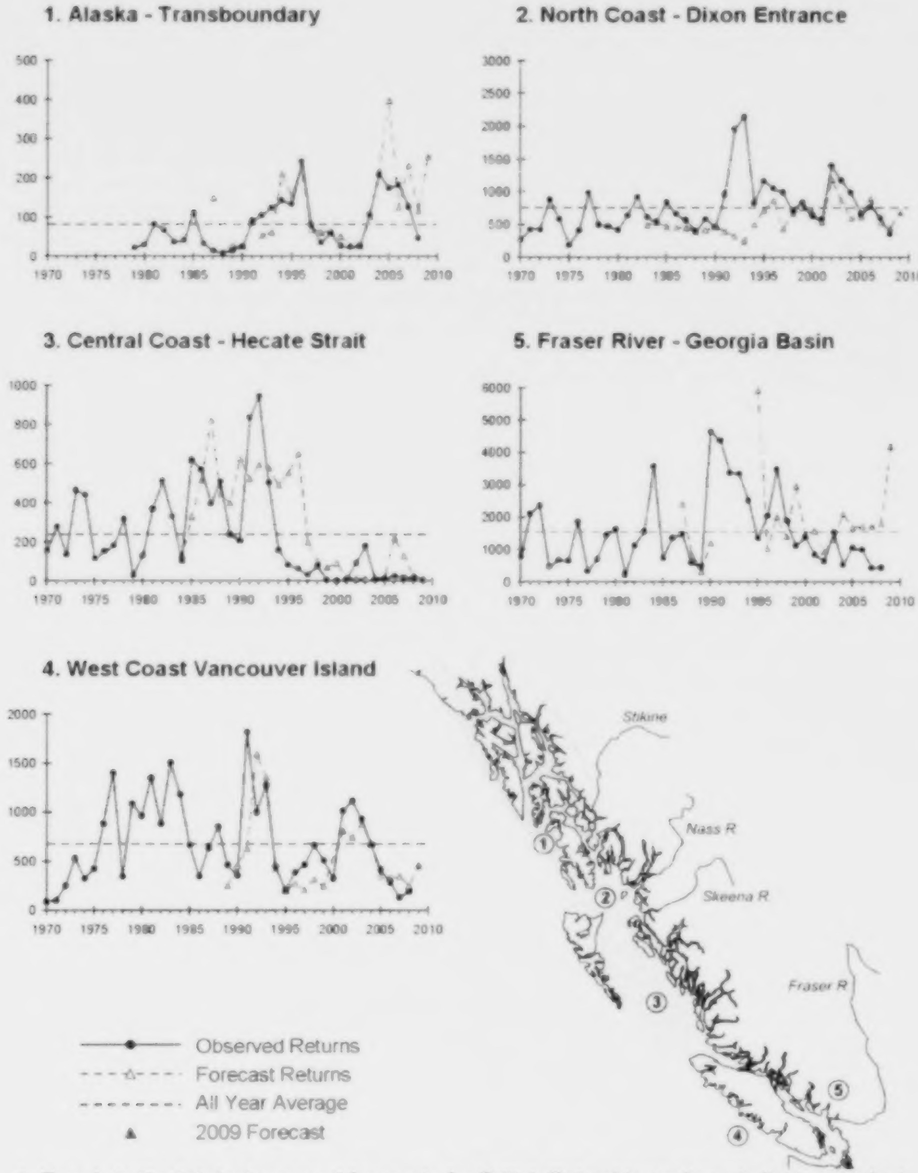


Figure 1. Trends in the total returns and forecasts for British Columbia sockeye indicator stocks including: 1. Tahltan, 2. Nass, 3. Smith's Inlet, 4. Barkley Sound, and 5. Chilko sockeye salmon. Y-axis represents returns in thousands of fish.

Sockeye Salmon Indicator Stocks –Regional Overview of Trends and 2008 Returns

Kim Hyatt, Margot Stockwell, and Paul Rankin, Fisheries & Oceans Canada

Results from recent studies (Mueter et al. 2002a, 2002b, Pyper et al. 2005) suggest that associations between Pacific salmon survival and near coastal environmental variables (upwelling index, sea surface temperature [SST], and sea surface salinity [SSS]) are strongest at local spatial scales (distances of less than 500-800 km) for adjacent stocks and exhibit little to no co-variation at spatial scales larger than 1000 km. Among three variables examined (upwelling, SST and SSS), correlation scales for SST in summer most closely matched the correlation scales for salmon survival. Furthermore, regional averages of SST appeared to be better predictors of survival rates than large-scale measures of SST variability such as the Pacific Decadal Oscillation (PDO; Mueter et al. 2002b). This suggests regional-scale variations in SST along the coast are related to the processes causing the observed co-variation in survival rates of neighbouring salmon stocks. Thus, neighbouring stocks are likely to exhibit stronger similarities in survival and production variations than stocks separated by larger distances. In addition, species comparisons suggested geographical overlap of salmon species during freshwater and early marine life stages are more important in determining shared environmental effects on survival rates (and ultimately on stock productivity) than are species differences (Pyper et al. 2005).

Comparisons of forecasts and observed returns of sockeye salmon returning to major rivers and fisheries throughout coastal British Columbia have been completed annually by DFO stock assessment personnel for decades (Figure 1). Given the observations noted above, production trends for major sockeye populations or stock aggregates (i.e. "indicator stocks") may reflect environmental changes and anticipate production trends for several salmon species originating from areas of the coast constituting separate production domains. Comparisons of trends for several sockeye indicator-stocks permit the following generalizations:

- Annual variability in total returns for all stocks is large with maximum annual returns ranging between 10 to 90 times the minimum return.
- Since 1970, maximum returns for all stocks occurred during the early 1990's immediately following the strong La Niña event of 1989.
- Central Coast, Vancouver Island (WCVI), and Fraser indicator-stocks all declined from early-1990s highs to persistent, sub-average returns since the mid-1990s (Figure 1).
- North Coast and Transboundary indicator-stocks declined from early-1990s highs, exhibited by all sockeye indicator-stocks, but relative to more southerly stocks, have remained closer to their all-year average return values since the late 1990s.
- Indicator-stocks entering continental shelf areas under stronger oceanic influences (i.e. areas 3 and 4 of Figure 1) appear more responsive to alternations in La Niña-like (anomalously cool, survival favourable) and El Niño-like (anomalously warm, survival less favourable) conditions (see detailed analysis for WCVI and Central Coast areas below) than stocks entering more protected estuarine waters (i.e. areas 1, 2, and 5 of Figure 1).
- All sockeye indicator stocks throughout the BC coast exhibited sub-average returns in 2008.
- Expectations for sub-average returns of North Coast (Nass), Central Coast (Long Lake), and WCVI (Barkley Sound) in 2008 were consistent with pre-season forecasts. By contrast, Transboundary (Tahltan) and Georgia Basin (Fraser-Chilko) indicator-stock returns were significantly lower than pre-season forecasts (i.e. areas 1 and 5 in Figure 1).
- Although there is some evidence of a return to near-average marine survival rates for 2006 sea-entry year smolts (returning as 4-year-old adults in 2008), uniformly sub-average

returns in 2008 continue to reflect a legacy of reduced returns and depressed spawner abundance associated with anomalously low smolt-to-adult survival during sea-entry years 2003-2005 (DFO 2006, 2007).

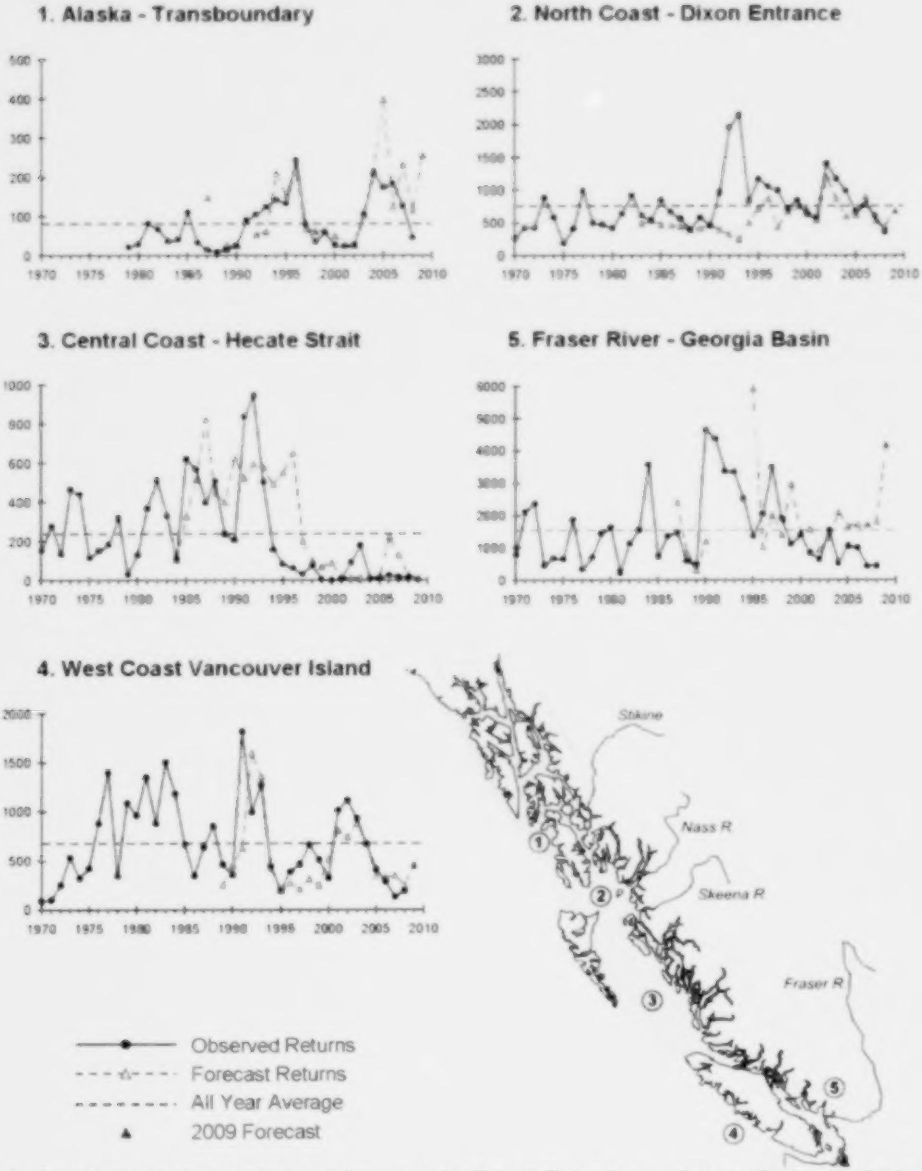


Figure 1. Trends in the total returns and forecasts for British Columbia sockeye indicator stocks including: 1. Tahltan, 2. Nass, 3. Smith's Inlet, 4. Barkley Sound, and 5. Chilko sockeye salmon. Y-axis represents returns in thousands of fish.

West Coast Vancouver Island

Barkley Sound Sockeye Salmon: Improving but still low returns

Barkley Sound (BkSd) sockeye on the west coast of Vancouver Island exhibit annual recruitment variations that alter abundance patterns by more than a factor of ten within intervals as short as 2-3 years (Figure 2). Studies of these variations have supported the use of a simple two-state, "survival-stanza", model since 1988 (SStM, Hyatt and Luedke 1999) to successfully predict multiyear intervals of stock collapse (late 1980's, mid-1990's, 2004-2007) and recovery (early 1990's, 2001-2003). SStM forecasts rely on the concept that continental-shelf ecosystems alternate between two states which support either high or low marine survival of juvenile sockeye respectively (Hyatt and Steer, 1988). Thus, "La Niña-like" conditions (SST < 30 yr average during smolt migration, low northward transport, average to below average sea level) are associated with relatively high marine survival (5 %) and "El Niño-like" conditions (SST > 30 yr average, elevated sea level, high northward transport) with lower marine survival (2.5 %).

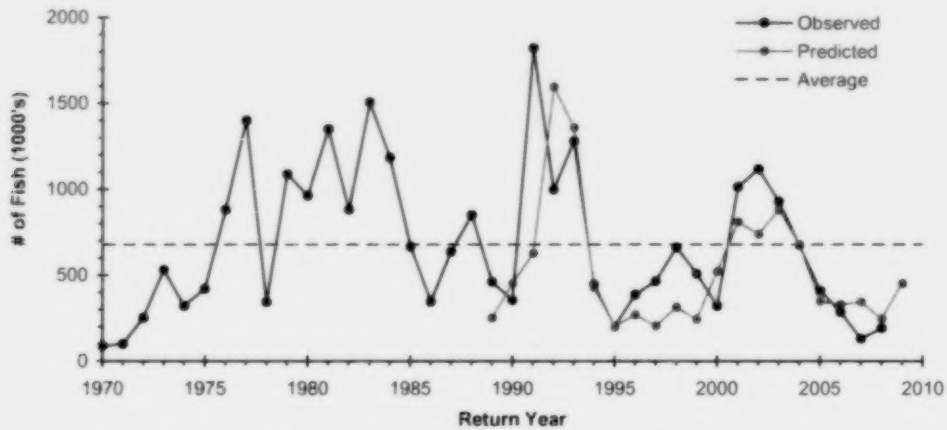


Figure 2. Returns and forecasts of Barkley Sound sockeye salmon 1974-2009.

NOAA's Northwest Fisheries Science Center (Ocean Ecosystem Indicators accessible at: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/g-forecast.cfm) has tracked La Niña-like and El Niño-like conditions in the Northern California Current (NCC) system that extends to the WCVI since 1998. The NOAA series of indicators form a "report card" for factors potentially associated with annual changes in marine survival of salmon during their sea-entry year into the NCC system (Figure 3). Although the suite of indicators employed have not been adapted for formal use in our forecasting system to date, a familiar "stop-light" classification matrix provides information to anticipate whether marine survival potential is above average (principally green), average (mixture of green, amber) or well below average (principally red). Reference to this matrix suggests that marine survival rates and associated returns for Barkley Sound sockeye that make sea-entry in the NCC system should have followed a trajectory with a trough in the year 2000, a peak during return years 2001-2003 followed by another trough between 2005 to at least 2007. The good correspondence between these expectations and observed returns is not surprising given our pre-existing knowledge of high and low marine survival states associated with La Niña and El Niño-like conditions (Hyatt and Steer 1988). However, the range of indicators tracked by NOAA offers additional information that may allow us to modify our two-state marine survival model into a multi-state model for improved performance.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Pacific Decadal Oscillation											
December-March	10	4	1	7	3	11	6	[illegible]	[illegible]	5	2
May-September	5	2	4	3	6	[illegible]	[illegible]	11	7	[illegible]	1
Multivariate El Niño Southern Oscillation Index											
MEI Annual	11	1	3	5	10	[illegible]	7	[illegible]	6	4	2
MEI Jan-Jun	11	2	3	5	7	[illegible]	6	10	4	[illegible]	1
Sea Surface Temperature											
Buoy 46050 (May-Sept mean)	9	2	4	5	1	7	11	[illegible]	6	10	3
NH 05 (May-Sept mean)	[illegible]	2	[illegible]	4	7	6	[illegible]	[illegible]	5	[illegible]	[illegible]
Winter prior to ocean entry	11	6	4	5	3	7	10	[illegible]	[illegible]	[illegible]	[illegible]
Physical Spring Transition (Logerwell)	7	6	2	1	4	[illegible]	[illegible]	11	[illegible]	3	5
Coastal Upwelling April-May	6	1	10	3	5	[illegible]	[illegible]	11	6	2	4
Deep Water at NH 05 (May-Sept)											
Temperature	11	4	6	2	3	7	8	10	[illegible]	5	1
Salinity	11	[illegible]	[illegible]	5	[illegible]	[illegible]	10	7	6	[illegible]	1
Upwelling Season Length (d)	7	4	[illegible]	[illegible]	1	10	[illegible]	11	6	5	[illegible]
Copepod Diversity	11	[illegible]	1	5	[illegible]	[illegible]	7	10	9	6	4
N Copepod Anomalies	11	8	3	5	2	[illegible]	6	10	7	4	1
Biol. Spring Transition	11	6	3	5	4	[illegible]	7	10	8	2	1
Spring Chinook (Jun)	10	2	3	8	5	7	[illegible]	11	6	4	1
Coho (Sept)	[illegible]	2	1	4	3	5	10	11	7	8	6
Overall Ranking											
Mean of ranks	9.5	3.5	3.2	4.6	4.3	8.6	8.0	9.7	6.9	5.1	2.4
Rank of mean ranks	10	3	2	5	4	[illegible]	[illegible]	11	7	6	1

Figure 3. Report card on factors influencing salmon survival in the Northern California Current (Northwest Fisheries Science Center (NOAA) Ocean Ecosystem Indicators at: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/g-forecast.cfm)

2008 Observations:

Barkley Sound sockeye salmon returns remained well below the long term average in 2005-2008 as predicted by the SStM model (Figure 2). Lower marine survivals experienced by WCVI juvenile salmon during their 2003-2005 ocean entry years (adult returns in 2005-2008) were anticipated by positive SST and ENSO indices respectively (DFO, 2005, 2006, 2007).

Outlook for 2009 and beyond:

In spring 2006-2008 sea surface temperature anomalies at Amphitrite Point, the NOAA multivariate ENSO index and NOAA "report card" (Figure 3) all reflected conditions that changed rapidly from ENSO-neutral (2006) to a very strong La Niña event (DFO 2007, 2007, 2008). Consequently, 2007-2008 sea-entry year return rates for Barkley Sound sockeye and several other salmon stocks (all WCVI origin sockeye stocks, Carnation Creek coho, Robertson Creek coho, and Chinook) are expected to exhibit significant, short-term, improvement. Increases in marine survival will permit a period of stock rebuilding for WCVI coho (2008-2009) and sockeye (2009-2010), but total returns are likely to remain sub-average (e.g. Barkley Sound sockeye in 2009, Figure 2) until depressed escapements are rebuilt.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Pacific Decadal Oscillation											
December-March	10	4	1	7	3	11	6	9	8	5	2
May-September	5	2	4	3	6	10	9	11	7	8	1
Multivariate El Niño Southern Oscillation Index											
MEI Annual	11	1	3	5	10	9	7	8	6	4	2
MEI Jan-Jun	11	2	3	5	7	9	6	10	4	8	1
Sea Surface Temperature											
Buoy 46050 (May-Sept mean)	9	2	4	5	1	7	11	8	6	10	2
NH 05 (May-Sept mean)	8	2	1	4	7	6	11	10	5	9	3
Winter prior to ocean entry	11	6	4	5	3	7	10	9	8	2	1
Physical Spring Transition (Logerwell)	7	6	2	1	4	9	8	11	9	3	5
Coastal Upwelling April-May	6	1	10	3	5	9	8	11	6	2	4
Deep Water at NH 05 (May-Sept)											
Temperature	11	4	6	2	2	7	8	10	9	5	1
Salinity	11	3	3	5	8	9	10	7	6	1	1
Upwelling Season Length (d)	7	4	3	9	1	10	8	11	6	5	2
Copepod Diversity	11	2	1	5	3	8	7	10	9	6	4
N Copepod Anomalies	11	8	3	5	2	9	6	10	7	4	1
Biol. Spring Transition	11	6	3	5	4	9	7	10	8	2	1
Spring Chinook (Jun)	10	2	3	8	5	7	9	11	6	4	1
Coho (Sept)	9	2	1	4	3	5	10	11	7	8	6
Overall Ranking											
Mean of ranks	9.5	3.5	3.2	4.6	4.3	8.6	8.0	9.7	6.9	5.1	2.4
Rank of mean ranks	10	3	2	5	4	9	8	11	7	6	1

Figure 3. Report card on factors influencing salmon survival in the Northern California Current (Northwest Fisheries Science Center (NOAA) Ocean Ecosystem Indicators at [illegible]).

2008 Observations:

Barkley Sound sockeye salmon returns remained well below the long term average in 2005-2008 as predicted by the SStM model (Figure 2). Lower marine survivals experienced by WCVI juvenile salmon during their 2003-2005 ocean entry years (adult returns in 2005-2008) were anticipated by positive SST and ENSO indices respectively (DFO, 2005, 2006, 2007).

<u>Outlook for 2009 and beyond:</u>

In spring 2006-2008 sea surface temperature anomalies at Amphitrite Point, the NOAA multivariate ENSO index and NOAA "report card" (Figure 3) all reflected conditions that changed rapidly from ENSO-neutral (2006) to a very strong La Niña event (DFO 2007, 2007, 2008). Consequently, 2007-2008 sea-entry year return rates for Barkley Sound sockeye and several other salmon stocks (all WCVI origin sockeye stocks, Carnation Creek coho, Robertson Creek coho, and Chinook) are expected to exhibit significant, short-term, improvement. Increases in marine survival will permit a period of stock rebuilding for WCVI coho (2008-2009) and sockeye (2009-2010), but total returns are likely to remain sub-average (e.g. Barkley Sound sockeye in 2009, Figure 2) until depressed escapements are rebuilt.

Central Coast – Queen Charlotte Sound

Rivers and Smith Inlet Sockeye Salmon: 2008 returns close to forecast, as anticipated (DFO 2008).

Rivers and Smith Inlet sockeye supported one of the most valuable fisheries on the Central Coast of BC until severe stock declines in the early to mid-1990s forced their closure. Time series assessments permitting partitioning of marine versus freshwater production stages (Author's data, Figure 4a) support the view (McKinnell et al. 2001) that the steep decline and low returns of sockeye to Rivers and Smith Inlets since the 1990s are due to persistently low marine survival. By contrast, a strong compensatory response of increased egg-to-fall-fry survival in freshwater (Smokehouse River, Canoe Creek, and Long Lake, Figure 4b) accompanied major reductions in spawner abundance for the 1997 to 2001 brood years and buffered Smith Inlet sockeye from even more severe declines.

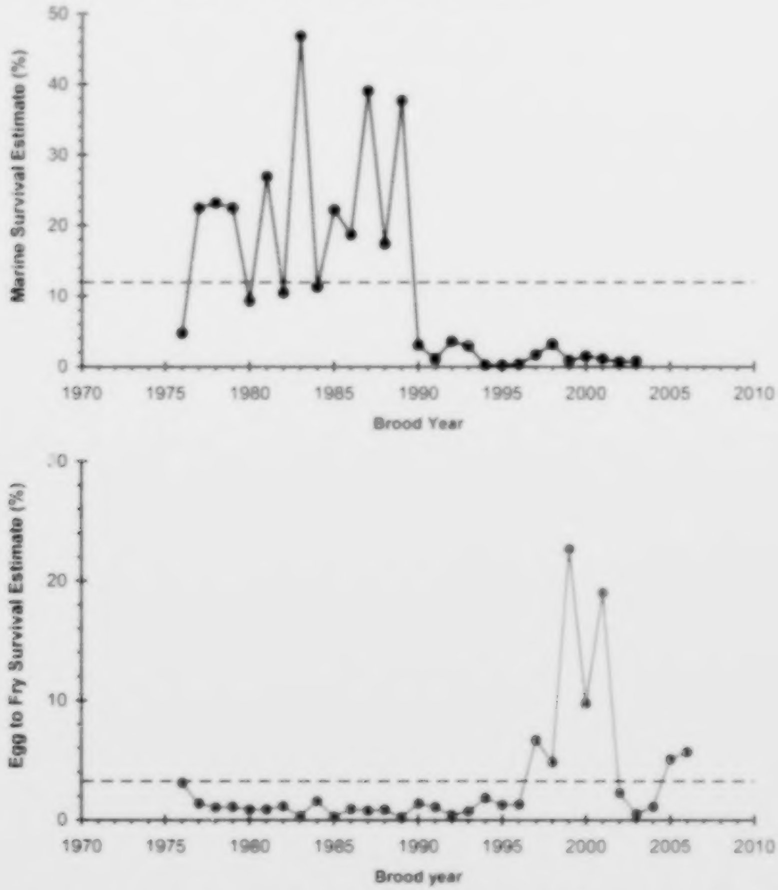


Figure 4. Trends in marine (smolt-to-adult) and freshwater (egg-to-fall-fry) survival of 1976-2006 brood year sockeye salmon from Smith Inlet (Long Lake).

Returns to Smith Inlet in 2008 remained strongly sub-average, as in 2004-2007 but much closer to the pre-season forecast (Figure 5).

Production trends for Central Coast sockeye appeared to share little in common with stocks from other areas prior to the mid-1980s. However, starting in the late 1980s both Barkley Sound and Central Coast indicator stocks (Figure 1) appear to reflect signature effects of alternating El Niño and La Niña -like events on production variations (i.e. shared peaks in 88, 91-93, 98, 02-03 associated with relatively cool SSTs during smolt migrations two years earlier; shared troughs in 89-90, 95-97, 02, 05-07 associated with relatively warm SSTs two years earlier). Thus, changes in ocean conditions within the past 15-20 years may have resulted in a northward expansion of common marine mechanisms controlling production variations for salmon stocks in the relatively open coastal waters of Barkley Sound (WCVI) and Queen Charlotte Sound (Central Coast). Application of a non-stationary, multi-state, survival model (SStM, Hyatt and Steer 1988) triggered by changes in SST has yielded relatively reliable forecasts of variations in Barkley Sound sockeye returns compared to the stationary models applied to Smith Inlet sockeye over a comparable interval (compare panels 3 and 4 in Figure1). WCVI and Central Coast survival rates are expected to improve under a variable-state, survival model. However, the depressed state of sockeye escapements in 2004-2005 and reduced smolt output in sea-entry years 2006 and 2007 make the continuation of sub-average total returns to Smith Inlet and Long L. very likely in 2009.

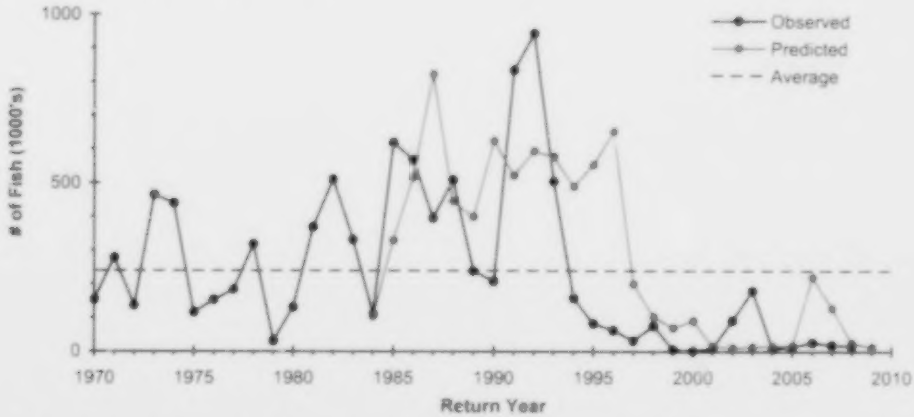


Figure 5. Returns and forecasts of Smith Inlet sockeye salmon, 1970-2009.

References

DFO 2005. State of the Pacific Ocean 2004. DFO Sci. Ocean Status Report. 2005/001.

DFO 2006. State of the Pacific Ocean 2005. DFO Sci. Ocean Status Report. 2006/001.

DFO 2007. State of the Pacific Ocean 2006. DFO Sci. Ocean Status Report. 2007/001.

Dobson, D., R. W. Tanasichuk and K. D. Hyatt. 2005. Forecast returns for Barkley Sound sockeye salmon to Great Central and Sproat lakes in 2005. PSARC Working Paper 2005-02 in DFO, 2005. Proceedings of the PSARC Salmon Subcommittee Meeting, March 3, 2005. DFO Can. Sci. Advis.Sec. Proceed. Ser. 2005/007. Available at www.dfo-mpo.gc.ca/csas/

Hyatt, K. D. and G. J. Steer. 1988. Stock status and 1988 forecasts of Barkley Sound sockeye. PSARC Working Paper S88-2.

Hyatt, K. D. and W. Luedke. 1999. West Coast Vancouver Island Sockeye. DFO Science Stock Status Rep. D6-05. 5p.
www.pac.dfo-mpo.gc.ca/sci/psarc/SSRs/diadromous_ssrs_e.htm

Hyatt, K. D., W. Luedke, J. Till, D. P. Rankin, and D. Lewis. 2000. Review of the 1999 return of Barkley Sound sockeye salmon and forecasts for 2000. PSARC Working Paper S2000-06. 29 p.

Hyatt, K. D., D. P. Rankin and B. Hanslit. 2000. Acoustic and trawl based estimates of juvenile sockeye salmon (Oncorhynchus nerka) production from 1976-199 brood year adults returning to Smith Inlet and Long Lake, British Columbia. PSARC Working Paper S2000-21.

Hyatt, K. D., K. Hunter, P. Rankin and M. Stockwell. 2007. Sockeye salmon index stocks- Regional overview of trends and 2006 returns pp. 57-61 in DFO 2007. State of the Pacific Ocean 2006. DFO Sci. Ocean Status Report. 2007/001.

McKinnell, S. M., C. C. Wood, D. T. Rutherford, K. D. Hyatt and D. W. Welch. 2001. The demise of Owikeno Lake sockeye salmon. N.Am.J.Fish.Mgt. 21: 774-791.

Mueter, F. J., D. M. Ware and R. M. Peterman. 2002a. Spatial correlation patterns on coastal environmental variables and survival rates of salmon in the north-east Pacific Ocean. Fish. Oceanogr. 11: 205-218.

Mueter, F. J., R. M. Peterman and B. J. Pyper. 2002b. Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (Oncorhynchus spp.) in northern and southern areas. Can. J. Fish. Aquat. Sci. 59: 456-463.

Pyper, B. J., F. J. Mueter, and R. M. Peterman. 2005. Across-species comparisons of spatial scales of environmental effects on survival rates of northeast Pacific salmon. Trans. Am. Fish. Soc. 134: 86-104.

Trends of Chinook in coast-wide fisheries managed under the Pacific Salmon Treaty

Gayle Brown, Rick McNicol and Chuck Parken, Fisheries & Oceans Canada

Under the jurisdiction of the Pacific Salmon Treaty (PST), 30 Chinook salmon stock aggregates and 25 fisheries distributed between southeast Alaska and northern Oregon are managed annually to either projected landed catch targets or are limited by maximum allowed exploitation rates. Estimates of escapements or terminal runs of mature fish for each of the stock aggregates and estimates of numbers of Chinook landed or released in the PST fisheries are assembled annually and provide some of the crucial data inputs to the calibration of the Coast-wide Chinook Model (CM). The Chinook stocks (comprised of both wild- and hatchery-origin fish) and PST fisheries represent nearly all Chinook and fishing-related impacts known to occur within the PST jurisdiction.

A result of the CM calibration procedure is a time series of aggregate Chinook abundance estimates for each of the PST fisheries starting with 1979 and ending with the most recently completed fishing year. An abundance forecast is also generated for the upcoming fishing year and is the basis for establishing the annual catch targets in three highly mixed-stock ocean fishery areas (southeast Alaska, Northern BC including areas around the Queen Charlotte Islands, and west coast Vancouver Island).

Time series of indexed abundance values (AIs) are annually derived and reported to the Pacific Salmon Commission (PSC) in technical reports prepared by the bilateral Chinook Technical Committee (e.g., TCCHINOOK 08(2), 2008 Annual Report of Catches and Escapements, Exploitation Rate Analysis and Model Calibration available at

http://www.psc.org/publications_tech_techcommitteereport.htm#TCCHINOOK).

The AIs are derived by dividing the annual estimated Chinook abundance in any one fishery by the average from the 1979-1982 'base period'. These provide a means of assessing temporal and spatial trends in the relative total abundance of Chinook stocks known to contribute to regional fisheries.

The time series of AIs for some of the major northern ocean fisheries (Figure 1) show generally that abundance has been consistently higher than in southern fisheries (Figure 2). More interestingly, Chinook abundance has reached a high of more than twice the base period average (BPA) in the most northerly fishery (southeast AK troll) and a low of less than half the BPA in the most southerly fishery (combined WA and OR ocean troll).

There have been two obvious peaks in abundance (1988 and 2003) in the two most northerly fisheries, SEAK troll and Northern BC troll, with lows just dipping below the BPA (Figure 1). Corresponding but much smaller peaks have occurred in some of the southerly fisheries (e.g., WCVI troll and WA/OR troll) but abundances have mostly been below the BPA (Figure 2).

Abundances in two 'inside' area fisheries, combined Georgia Strait and Juan de Fuca sport in BC and northern Puget Sound sport in WA, declined below their BPA early in the time series, with the decline beginning sooner in BC waters (1985 vs 1990). The decline has also been more persistently severe in BC waters. Abundances in recent years in the four southern fisheries have been well below BPAs.

The 2009 CM calibration projects a modest increase for most Chinook fisheries coast-wide. The most notable increase is at the northern end of the PST jurisdiction (Southeast Alaska troll) and the most notable decrease is at the southern end (Washington/Oregon troll).

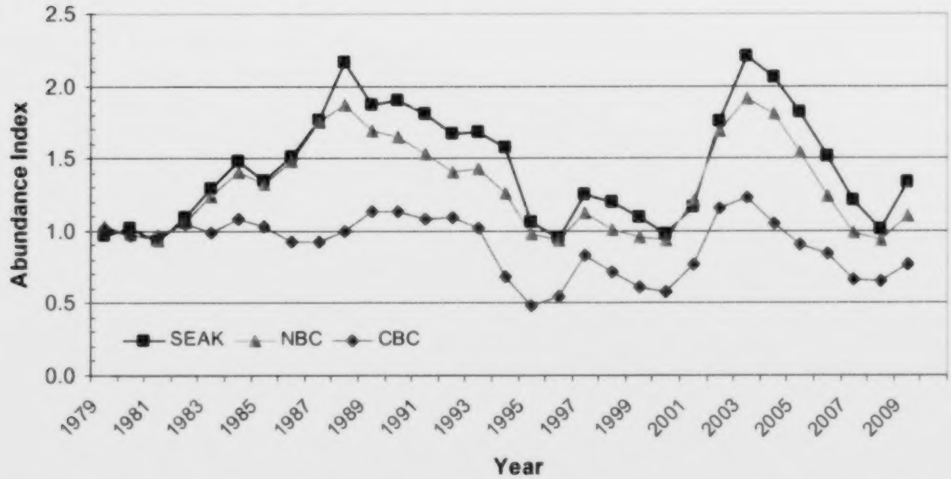


Figure 1. Time series of Chinook Index Abundance Values (AI), 1979-2009 for three major northerly Pacific Salmon Treaty (PST) fisheries. The fisheries are southeast Alaska troll (SEAK), northern BC troll in statistical areas 1-5 (NBC) and central BC troll in statistical areas 6-12 (CBC). Please note that 2009 values are forecasts resulting from the March 2009 calibration of the Coast-wide Chinook Model.

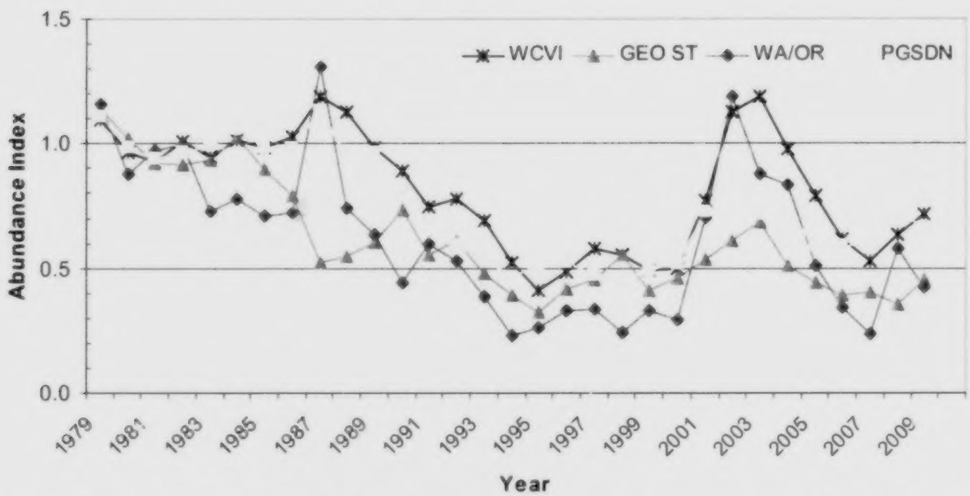


Figure 2. Time series of Chinook Index Abundance Values (AI) 1979-2009 for four southerly PST fisheries. The fisheries are west coast Vancouver Island troll (WCVI), Georgia Strait and Juan de Fuca Sport (GEO ST), Washington and northern Oregon ocean troll (WA/OR) and northern Puget Sound sport (PGSDN). As in Fig.1, the 2009 values are forecasts.

Trends in marine life of Pacific Rim National Park Reserve

Yuri Zharikov, Heather Holmes, Bob Hansen and Peter Clarkson
Resource Conservation – Ecosystem Secretariat,
Pacific Rim National Park Reserve of Canada

Introduction

Pacific Rim National Park Reserve of Canada is located on the west coast of Vancouver Island between the towns of Tofino and Port Renfrew. It has the mandate to monitor and report on the state of its ecological integrity of marine and terrestrial ecosystems within the Park bounds (PCA 2008). The Park monitors 33 measures of ecological integrity, where a measure represents a population of animals or an environmental parameter, such as water quality. Of these, 15 measures belong to the subtidal and intertidal ecosystems, i.e. ecological space located between the high-tide mark and the 20-fathom depth contour representing the seaward extent of the Park. For the purpose of this report we include information on several marine biota for which data sets of more than 10 years are available.

Bivalves:

A select group of native and exotic bivalves is being monitored in the intertidal sediments of the Broken Group Islands Unit of the park. Native species include the Butter Clam (*Saxidomas gigantea*), Littleneck Clam (*Protothaca stamina*), and the Olympia Oyster (*Ostrea conchaphila*). Exotic species include the Manilla Clam (*Tapes philippinarum*), Varnish Clam (*Nutallia obscurata*), and the Japanese Oyster (*Crassostrea gigas*). Clams are sampled by placing 15 random 0.25 m^2 quadrats relative to a baseline established across the mid-intertidal zone within a site, once a year at four permanent sites. Oysters are likewise sampled one a year at two or three sites by complete counts in 6 random 1 m^2 plots per site laid out along a transect bisecting the oyster-bed. Bivalve sampling started in 1997.

Regression and ANCOVA analyses suggested that three clams (Butter, Littleneck and Manila) displayed no particular trend over the 10-year period on a per site basis (Fig. 1). The same was true for the overall abundance of Littleneck and Manila clams (Fig. 2). Butter Clams seem to show a general decline in the past 7 years. Year 2006 had higher than average densities in the Littleneck and Manila Clams.

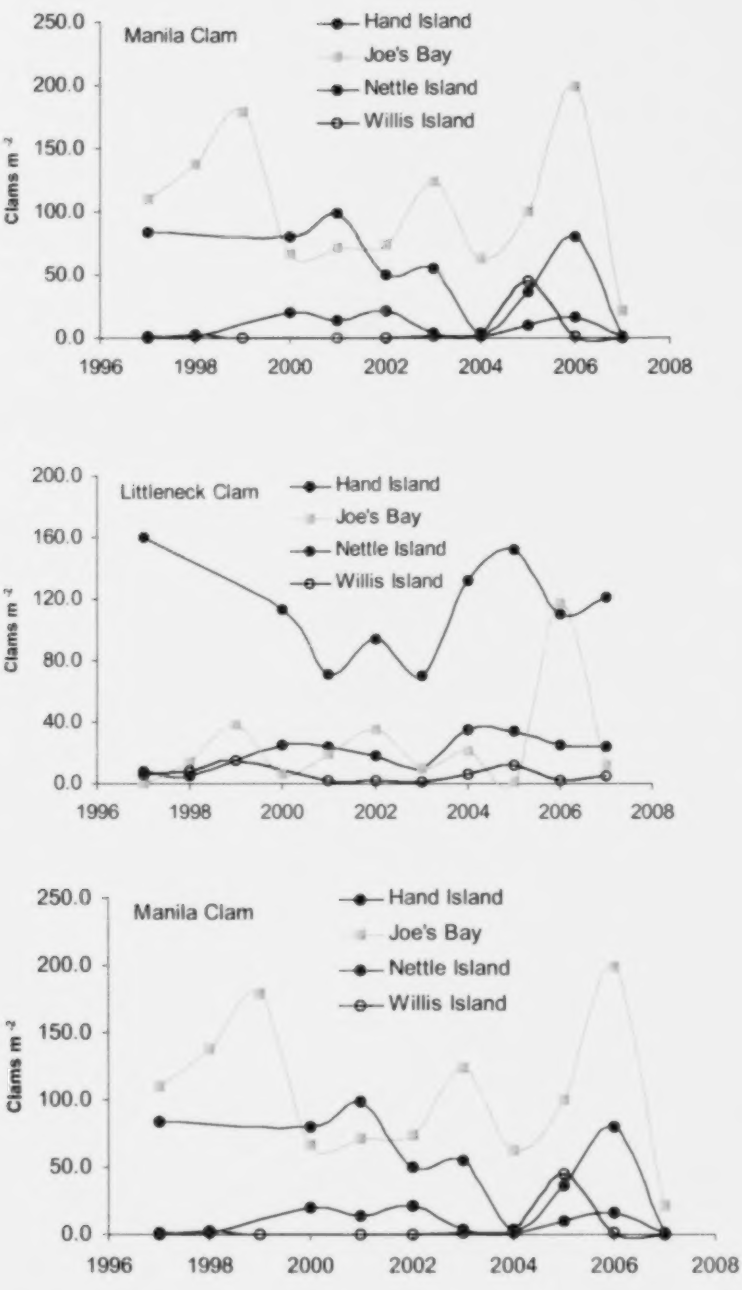


Figure 1. Site-specific clam densities in the Broken Group Islands Unit of Pacific Rim National Park Reserve.

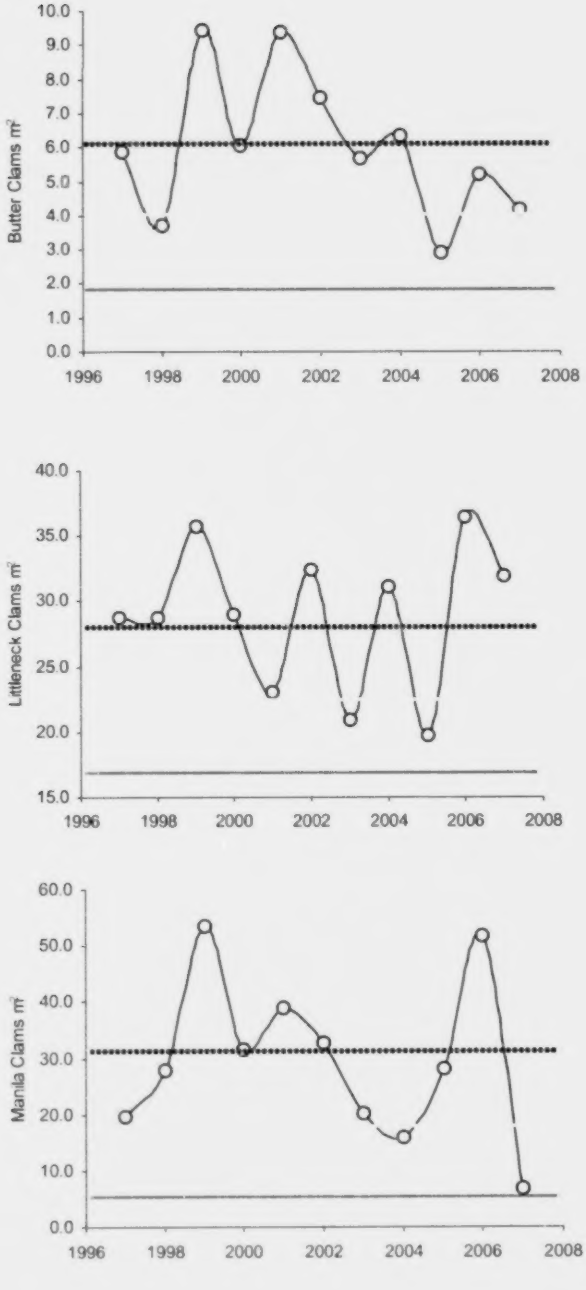


Figure 2. Overall clam densities in the Broken Group Islands Unit of Pacific Rim National Park Reserve – dashed line represents the overall mean, while the yellow and red lines are 1 and 2 standard deviations from the mean respectively.

The three other species, however, displayed statistically significant trends. The overall density of the exotic Varnish Clam has increased 8-fold from mid 1990s (Fig. 3) while no Varnish Clams were recorded in the Park in 1978. Year 2006 also had a high recruitment of these bivalves.

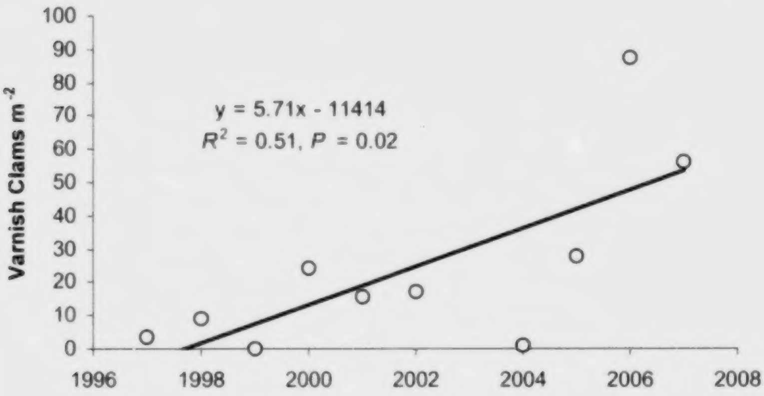


Figure 3. Overall Varnish Clam density in the Broken Group Islands Unit of Pacific Rim National Park Reserve.

On the other hand the density of the Olympia Oyster has declined sharply over the past 10 years, without noticeable recruitment events (Fig. 4).

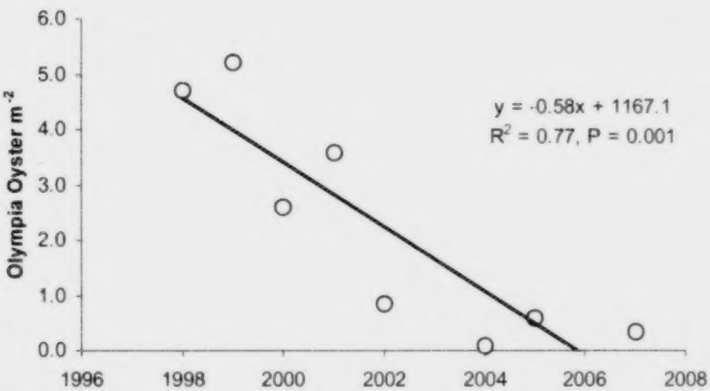


Figure 4 Overall Olympia Oyster density in the Broken Group Islands Unit of Pacific Rim National Park Reserve.

Japanese Oysters declined at two sites out of the three resulting in an overall mild decline over the past 10 years (Fig. 5).

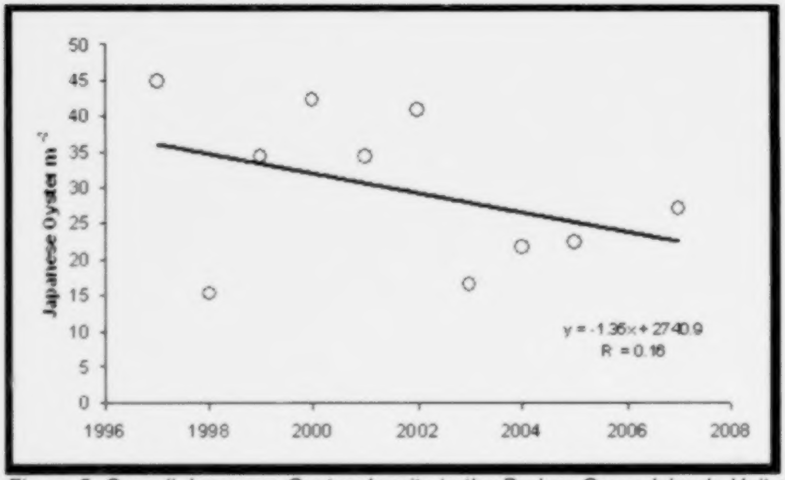


Figure 5. Overall Japanese Oyster density in the Broken Group Islands Unit of Pacific Rim National Park Reserve.

Seabirds

At-sea seabird surveys were conducted in the Park in May - September 1994 - 1996 and 1999 – 2008 along three transects (total length – ca. 700 km). In this report we were concerned only with the annual trends in seabird populations occurring in the Park waters, but not with their distribution patterns within a season and/or year. Given the mobility of seabirds and their ability to travel over dozens of kilometres in search of food on a daily basis, we felt that the three seabird transects that have been surveyed in the Park – two at Broken Group Islands and one along the West Coast Trail – are representative of one and the same population. Thus, the transect-specific counts were combined into one length-adjusted density estimate (birds/km) when all three transects were surveyed within a 2-week period. This resulted in 1 to 8 of such complete surveys per year.

In all analyses the mean annual density estimate was used as a data point, i.e. annual data were pooled (n = 1 – 8 surveys). Only individuals sitting or flying within 150 m from the boat were included. Only breeding period (May – July) data were analyzed, because the local abundance of the species drops off dramatically in late summer and fall. Pacific Herring data that we used to contrast seabird abundance were kindly provided by Ron Tanasichuk of the Fisheries and Oceans Canada. These are the same data that were used in the 2007 State of the Ocean Report.

Regression analyses suggested that out of the six common species of seabirds for which Pacific Rim National Park has long-term data, four – Marbled Murrelet (*Brachyramphus marmoratus*), Surf Scoter (*Melanitta perspicillata*), Pelagic Cormorant (*Phalacrocorax pelagicus*) and Rhinoceros Auklet (*Cerorhinca monocerata*) have declined or continue to decline as compared to mid 1990s (Fig. 6). For example, the population of Marbled Murrelets has been declining at the rate of 10% per annum with a total reduction in the population between mid-1990s and mid-2000s of 68% (Fig. 6). In at least three of the species that feed on pelagic forage fish and zooplankton (Marbled Murrelet, Pelagic Cormorant and Rhinoceros Auklet), the recorded numbers mirror biomass estimates for the Herring. Much of the decline seems to be associated with the collapse of local Pacific Herring stocks.

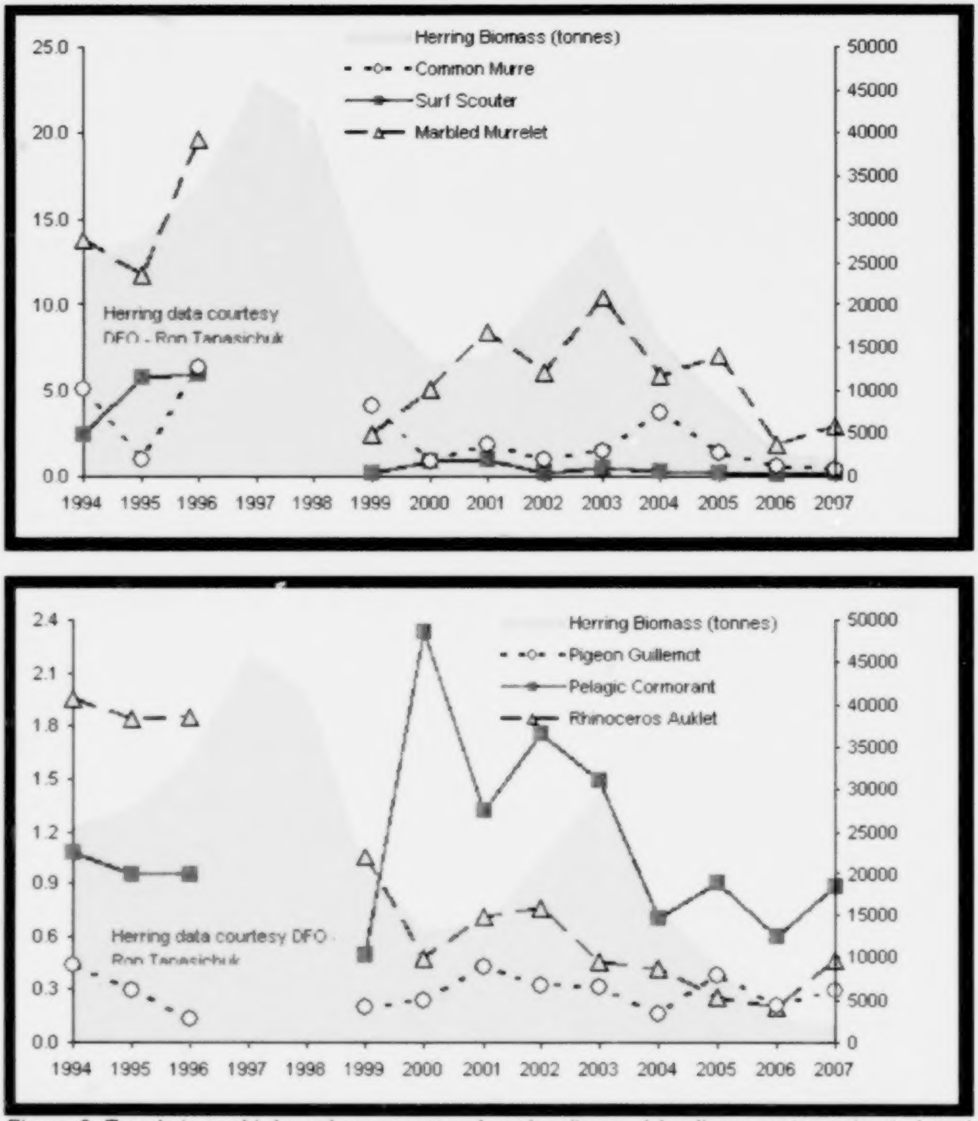


Figure 6. Trends in seabird numbers expressed as density per 1 km linear route contrasted against local Herring stocks (blue background). Red trends indicated species with statistically significant population declines. Blue trends refer to relatively stable populations within Park waters.

Nesting Glaucous-winged Gulls (*Larus glaucescens*) are annually counted in the Park at four main colonies since 2007. Based on the available data (Fig. 7), it is apparent that two larger Glaucous-winged Gull colonies in the Park – Florencia Island and Seabird Rocks – experienced steep population declines in late 1960s – early 1970 (although large data gaps make this assessment qualitative). It appears the Seabird Rock colony collapsed first with many birds moving to Florencia Island, with the latter colony succumbing to the agent of decline by 1975.

The timing of these declines in 60s and 70s coincided with the coast-wide collapse of Pacific Herring stocks (DFO 2007) potentially providing a causal mechanism for the observed pattern; a strong relationship between human fishing activities and demographics of seabirds is a well-established phenomenon (e.g. Diamond & Devlin 2003; Frederiksen et al. 2004; Norris et al. 2007). Why the other two smaller colonies, Sea Lion Rocks and White Island, remained stable is difficult to explain. One could suggest that the gulls occupying these colonies relied on sources of food other than individuals from the affected colonies.

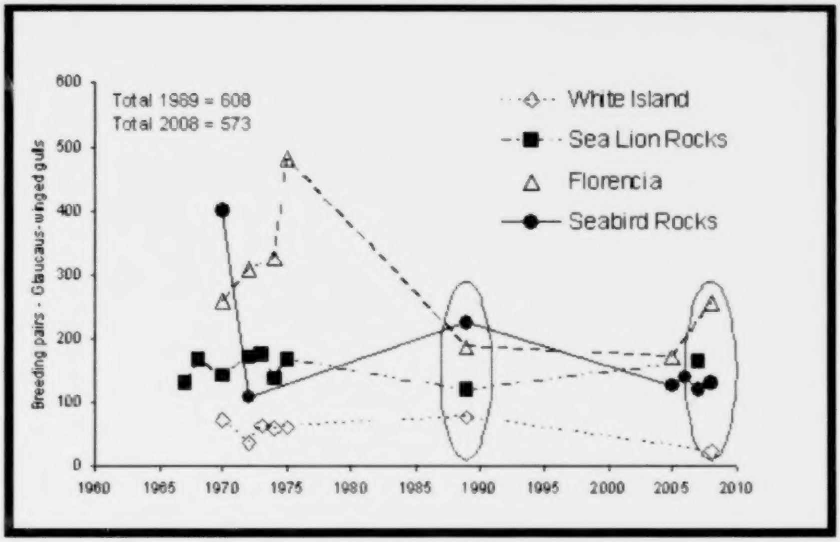


Figure 7. Abundance of Glaucous-winged Gulls (breeding pairs) at four colonies in Pacific Rim National Park Reserve.

Post mid-1970, populations of the Glaucous-winged Gull in the Park stabilized at a somewhat lower level of approximately 600 pairs versus ca. 900 around 1970 and remained constant from 1989 to present. The decline may actually have been a positive development and two points are worth noting with this regard. (1) The high population levels in 1970s may have been artificial due to increased food provisioning in the form of fisheries discard and offal (Garthe, Camphuysen & Furness 1996) and/or through high fisheries pressure on large predatory fish which in turn released forage fish populations (Furness 1982). Thus in early 1970s the gull population may have returned to a "natural" level. (2) The gull declines on Florencia and Seabird Rocks were accompanied with rapid colonization of these two locations by Black Oystercatchers (*Haematopus bachmani*), whose nesting requirements are similar to those of the gulls (PCA 2008).

Marine mammals

Grey Whales (*Eschrichtius robustus*) are monitored since 1997 as one of several measures in the subtidal ecosystem. The animals are photographed and then identified to the individual level using patterns of scratches, scars, and growths of barnacles and whale lice (Bigg et al. 1987).

Grey Whale numbers (Barkley – West Coast Trail) fluctuated widely from 2 - 40 individuals and remain overall stable. For example 30 or more grey whales were observed in years 1998, 2005

and 2006, while only 2 and 3 individuals were recorded in 2001 and 2007, respectively. In 2008, 46 individuals have been recorded (not in the figure), which is the record count for the Park. In 1997 - 2004 the whale numbers tracked herring biomass, but the relationship became decoupled in 2005 and 2006 when herring numbers plummeted (Fig. 8).

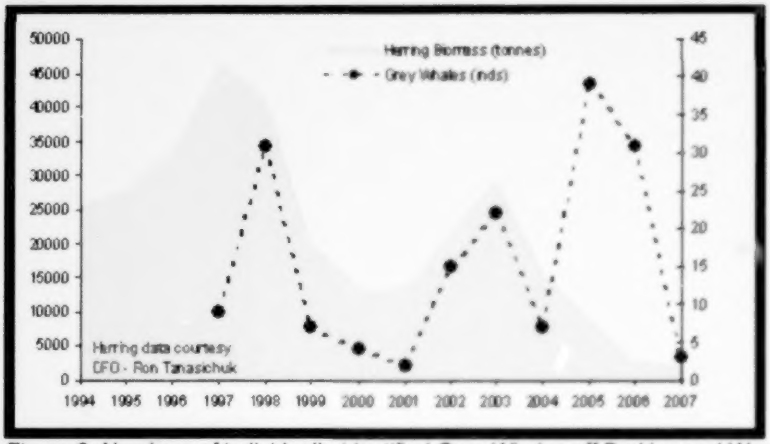


Figure 8. Numbers of individually identified Grey Whales off Barkley and West Coast Trail

Conclusions

Although different animals displayed different trends in terms of increasing and decreasing abundance, many higher-trophic level vertebrates (birds) had negative abundance trends in the waters of Pacific Rim National Park Reserve over the past decade. Of note also is expansion of the Varnish Clam – a species alien to the area. Grey Whales have been fluctuating widely in the past 5 years and the reason for this is unclear.

References

Bigg, M.A., Ellis, G.M., Ford, J.K.B., & Balcomb, K. (1987) Killer Whales: A Study of Their Identification, Genealogy and Natural History in British Columbia and Washington State. Phantom Press, Nanaimo.

DFO (2007) State of the Pacific Ocean 2006. Department of Fisheries and Oceans - Ocean Status Report 2007/001; www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm.

Diamond, A.W. & Devlin, C.M. (2003) Seabirds as indicators of changes in marine ecosystems: ecological monitoring on Machias Seal Island. Environmental Monitoring and Assessment, 88, 153-175.

Frederiksen, M., Wanless, S., Harris, M.P., Rothery, P. & Wilson, L.J. (2004) The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. Journal of Applied Ecology, 41, 1129-1139.

Furness, R.W. (1982) Competition between fisheries and seabird communities. Advances in Marine Biology, 20, 225-307.

Garthe, S., Camphuysen, K. & Furness, R.W. (1996) Amounts of discards by commercial fisheries and their significance as food for seabirds in the North Sea. Marine Ecology Progress Series, 136, 1-11.

Norris, D.R., Arcese, P., Preikshot, D., Bertram, D.F. & Kyser, T.K. (2007) Diet reconstruction and historic population dynamics in a threatened seabird. J. of Appl. Ecol., 44, 875-884.

PCA. 2008. Pacific Rim national Park Reserve of Canada, State of the Park Report. Parks Canada Agency. http://www.pc.gc.ca/pn-np/bc/pacificrim/images/rsep-sopr2008_e.pdf

Highest catches of juvenile salmon off Vancouver Is., but average growth conditions

Marc Trudel, Steve Baillie, Chuck Parken, and Dave O'Brien
Fisheries & Oceans Canada

Ocean surveys for juvenile salmon have been used to assess the distribution, growth, condition, and survival of Pacific salmon in different parts of the British Columbia coastal ecosystem since 1998. These surveys are usually conducted in late spring-early summer (June-July) and in the fall (October-November). In addition, juvenile salmon have been collected during winter (February-March) since 2001. The general assumption of this work is that marine survival is expected to be high in years when salmon are rapidly growing and are in good condition and low in years of poor growth and condition. Hence, marine survival is expected to be positively correlated to indicators of juvenile salmon growth rate.

June-July 2008 catch-per-unit-effort of juvenile Chinook, sockeye and chum salmon off the west coast of Vancouver Island were the highest on record since 1998 by nearly a factor of ten, and the third highest for juvenile coho salmon (Fig. 1). This suggests that early marine survival was consistently high for all the species of salmon in 2008 in this area. Thus, adult returns are expected to be high in 2009 for coho salmon, in 2010-2011 for Chinook and sockeye salmon, and in 2011 for chum salmon. However, the predictions for Chinook salmon are only applicable to Columbia River spring Chinook salmon, as these are the stocks we normally catch during our June-July surveys. In contrast to 2008, catch-per-unit effort of juvenile salmon off the west coast of Vancouver Island in 2005 were generally the lowest on record for most species (Fig. 1), suggesting poor marine survival for the smolts that migrated to sea that year. This may explain the poor returns of several stocks of salmon in recent years.

These surveys also indicate that juvenile coho salmon are generally growing faster in Southeast Alaska than off the west coast of Vancouver Island (Fig. 2). This could potentially explain the higher marine survival of southeast Alaska coho salmon compared to southern British Columbia stocks. In 2008, the growth rate of juvenile coho salmon was near the 1998-2008 average value off the west coast of Vancouver Island and Southeast Alaska (Fig. 2). Our analyses indicate that the marine survival of west coast of Vancouver Island coho, Chinook, and sockeye salmon is strongly correlated to the growth conditions for coho salmon in this region (Trudel et al. 2008). Hence, taken together, summer catches and growth and coho growth suggest that marine survival will be average to better than average for west coast of Vancouver Island coho salmon returning in 2009 relative to 1999-2008, as well as for west coast of Vancouver Island Chinook salmon and for Barkley Sound sockeye salmon in 2010 relative to 2000-2008.

References

Trudel, M., Thiess, M.E., Bucher, C., Farley, E.V., Jr., MacFarlane, B., Casillas, E., Morris, J.F.T., Murphy, J.M., and Welch, D.. 2007. D.W. Regional variation in the marine growth and energy accumulation of juvenile Chinook salmon and coho salmon along the west coast of North America. Am. Fish. Soc. Symp. Ser. 57: 205-232.

Trudel, M., Baillie, S., Parken, C., and O'Brien, D. 2008. Average growth for coho salmon in southern BC. pp. 82-83 In Irvine, J. and B. Crawford (Eds). 2008. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. Canadian Science Advisory Research Document 2008/013: (http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm)

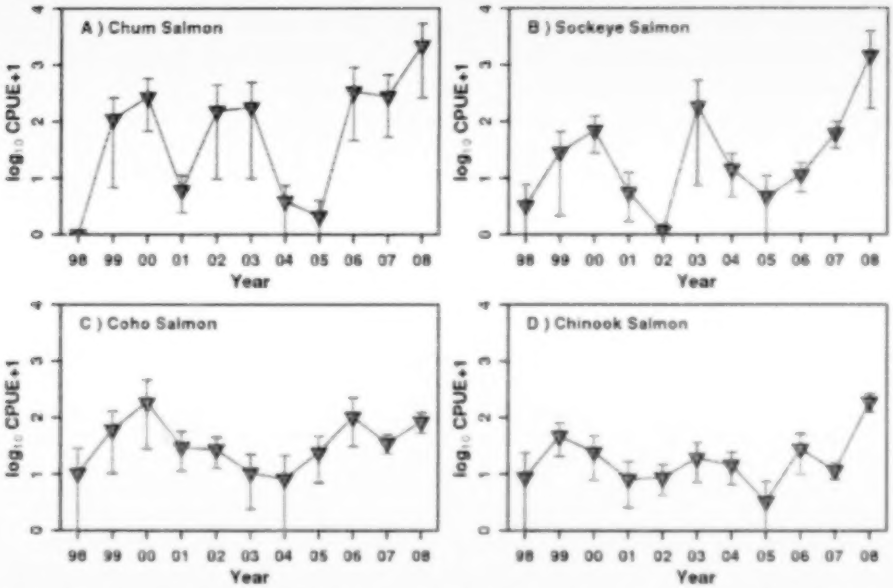


Figure 1. Catch-per-unit-effort (CPUE) of juvenile chum, sockeye, coho and Chinook salmon on the continental shelf off the west coast of Vancouver Island in June-July 1998-2008. Average CPUE and 95% confidence intervals were obtained by bootstrap.

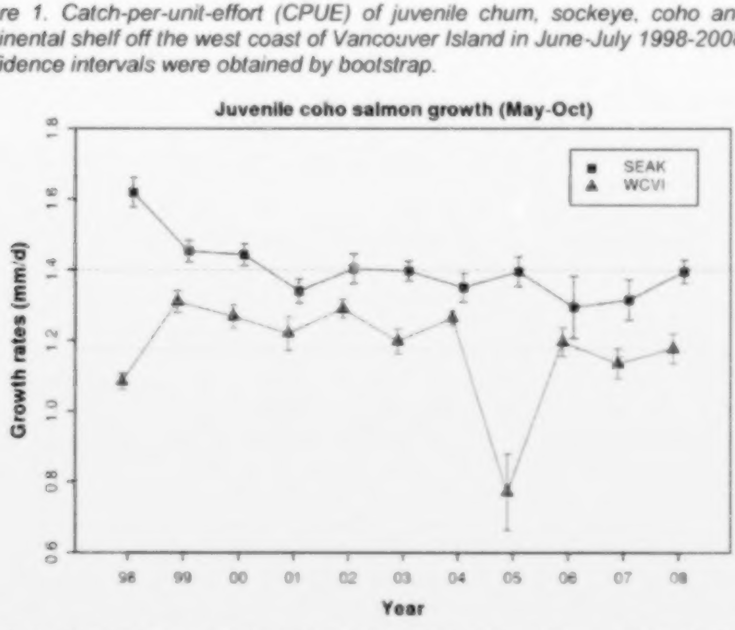


Figure 2. Growth rates (May-October) of juvenile coho salmon off the west coast of Vancouver Island (red triangles) and Southeast Alaska (blue squares). The blue and red dotted lines represent the 1998-2008 average values for Southeast Alaska and the west coast of Vancouver Island, respectively. The error bars are 2 x SE. Details on the procedure used to estimate growth rate are provided in Trudel et al. (2007).

Ocean recovery of two end ngered sockeye stocks

Marc Trudel, Fisheries & Oceans Canada

Little is currently known on the ocean distribution and migration of endangered or threatened stocks of sockeye salmon, thus making it difficult to assess how ocean conditions affect the recruitment of these stocks, and hence, to forecast their returns. The mass marking of endangered and threatened stocks of sockeye salmon in recent years with coded-wire tags (CWT) now makes it possible to track their ocean migration. Although the likelihood of capturing these sockeye salmon smolts in research surveys was considered to be negligible given their low abundance relative to healthy stocks, in June 2008 we recovered two juvenile Redfish Lake sockeye salmon off the coast of British of Columbia, and one on July 1, 2007 (Table 1; Fig. 1). This stock is listed under the Endangered Species Act (ESA) since 1991 (NRC 1996; NMFS 2009). These fish traveled approximately 1,450 km in the Snake River and Columbia River and another 350-1,050 km in the ocean in less than 60 days. Hence, the combined river and ocean migration speed, assuming that these fish were swimming in a straight line, ranged from 40 km/d to 49 km/d, or 3.5-3.7 body length per seconds (Table 1). This is about twofold faster than their theoretical optimal cruising speed at 10°C (Trudel and Welch 2005), indicating that that they undertake a rapid northward migration that quickly brings them well beyond the Columbia River Estuary and Plume to expose them to ocean conditions prevailing on the west coast of British Columbia, and subsequently to those in Alaska.

In addition to juvenile Redfish Lake sockeye salmon, we recovered five adipose-fin clipped juvenile sockeye in June 2008 and one in July 2007 in our integrated pelagic ecosystem surveys (Table 1). Two of these had been tagged by DFO with an agency code only CWT. These two juvenile sockeye salmon likely originated from Cultus Lake, a stock that has been listed as Endangered under the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in British Columbia (Irvine et al. 2005). The origin of the remaining three adipose-fin clipped juvenile sockeye salmon caught in 2008 is currently unknown. The presence of endangered stocks in our catches combined with the highest catch-per-unit effort of juvenile sockeye salmon since 1998 strongly suggests that early marine survival was high for the sockeye smolts that migrated to sea in 2008, and that we may expect higher returns for Cultus Lake and Redfish Lake sockeye salmon in 2010 if they mature as age four.

References

Groot C., and L. Margolis. 1991. Pacific salmon life histories. UBC Press, University of British Columbia, Vancouver, British Columbia.

Irvine, J. R., M. R. Gross, C. C. Wood, L. B. Holby, N. D. Schubert, and P. G. Amiro. 2005. Canada's Species at Risk Act: An opportunity to protect "endangered" salmon. Fisheries 30:11-19.

National Research Council. 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington D.C.

National Marine Fisheries Service. 2009. Species under the Endangered Species Act (ESA). (http://www.nmfs.noaa.gov/pr/species/esa/fish.htm - last access on March 18, 2009).

Trudel, M., and D.W. Welch. 2005. Modeling the oxygen consumption rates of Pacific salmon and steelhead trout: model development. Trans. Am. Fish. Soc. 134: 1542-1561.

Table 1. Recovery location of juvenile coded-wire tagged Cultus Lake (CL) and Redfish Lake (RL) sockeye salmon and estimated migration distance and dispersion speed.

Origin	Tag code	Recovery Date	FL (mm)	Latitude	Longitude	Distance (km)	Speed (km/d)
RL	10-82-77	07/01/2007	162	54°15' N	131°41' W	2,515	46.5
RL	10-17-81	06/21/2008	138	49°03' N	126°07' W	1,800	40.0
RL	09-46-29	06/28/2008	193	54°28' N	131°36' W	2,530	48.6
CL*	18	06/28/2008	176	54°33' N	132°22' W	1,005	17.3**
CL	18	06/28/2008	176	54°26' N	131°24' W	956	16.5 **

* Two additional adipose-fin clipped juvenile sockeye salmon were caught at this station, but did not have coded-wire tags.
** Cultus Lake sockeye smolts were assumed to initiate their downstream migration on May 1 (Groot and Margolis 1991).

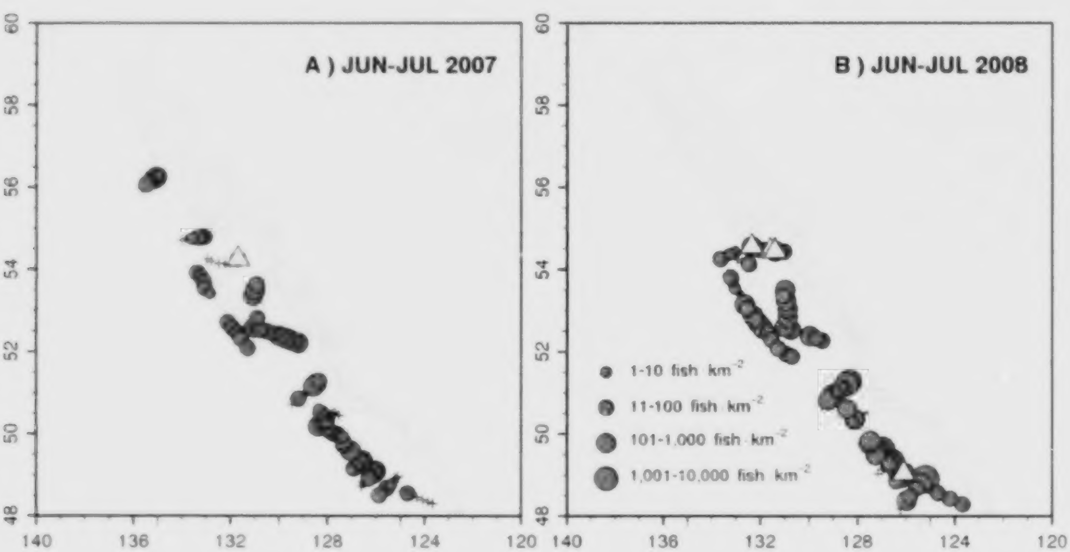


Figure 1. Distribution of juvenile sockeye salmon caught in British Columbia and southeast Alaska in June-July of 2007 and 2008. Juvenile sockeye salmon were caught using a rope trawl towed at the surface for 30 minutes at 5 knots. Sampling effort was limited to the continental shelf, as previous surveys indicated that juvenile sockeye salmon were restricted to the continental shelf at this time of year. The size of the red circles is proportional to the catch-per-unit effort (number of juvenile sockeye salmon per square kilometre). The black plus sign indicate stations where no juvenile sockeye salmon were caught, whereas the green triangles represent the recovery location of coded-wire tagged juvenile sockeye salmon.

Coho – Southern BC Populations Doing Poorly but Some Survival Improvements Expected

Jim Irvine[1] and Dave Blackbourn[2],
[1]Fisheries and Oceans Canada and [2]private consultant, Nanaimo

Coho marine survival data were assembled for hatchery and wild populations from: South-East Alaska (SEAK), North Coast BC (NCBC), Central Coast BC (CCBC), West Coast Vancouver Island (WCVI), Strait of Georgia (SOG), Puget Sound and Hood Canal (PSWA), and Columbia River (COL) (Fig. 1).

Coho from SEAK and NCBC exhibited similarly variable survivals with no significant trend. Alaska coho survived at consistently higher rates than those from NCBC. Coho from PSWA and SOG both experienced significant declines over the time series; PSWA coho survived at higher rates than SOG coho. Coho from WCVI survived better than coho from further south (WCWA). Survival declines for WCVI coho were significant. Coho survivals from CCBC and COL had no trend (Fig. 1).

Recent annual marine survivals were correlated with a wide variety of environmental variables. Only the strongest of these comparisons are shown, with the size of the boxes corresponding to one of two categories of levels of the value of 'r'. All comparisons shown had uncorrected probability values <0.05. Forecasts with the strongest potential predictive power were categorized as: red - survivals well below average since 1996; yellow – rates within half a standard deviation of the average value; and green – rates well above the average (Fig. 2).

Relatively good survivals are forecast for coho returning in 2009 (Fig. 2). Possible exceptions are for SOG and SEAK coho that each experienced mixed signals. It is important to realize that good survivals do not necessarily mean good returns. Coho returning in 2009 are the progeny of coho that went to sea in the spring of 2005, many of which experienced extremely low survivals.

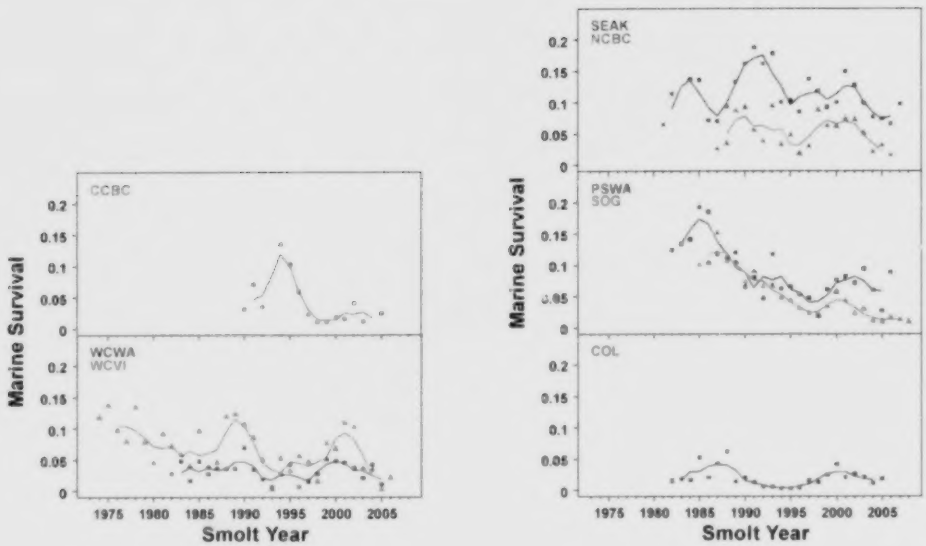


Figure 1. Coho marine survival time series for the entire time period (3 yr moving averages).

In 2008 smolt year	SEAK	NCBC	WCVI	SOG	PSWA	WCWA	COL
PDO							
Northern SST							
Northern SSS							
Southern SST							
Southern rain							
VI boreal copepods							
ORE bio transition							
ORE copepod diversity							

If 0.60 ≤ r ≤ 0.75 If r >0.75 Good Average Poor

Figure 2. Predictors for coho marine survival rates for 2009 return year – based on data from 1996 to the present.

Thanks to Leon Shaul (ADFG), Steve Baillie, Roberta Cook and Joel Sawada (DFO), and Jeff Haymes (WDFW) for providing coho survival data, and Joe Orsi, Frank Thrower, and Bruce Wing (NMFS – Alaska) and David Mackas (DFO) for providing environmental data.

Albacore tuna in BC waters: Cool waters, fewer tuna in 2008

John Holmes, Fisheries & Oceans Canada

Albacore tuna (*Thunnus alalunga*) is a widely distributed, highly migratory, and economically important tuna species found in the subtropical and temperate waters of the Pacific Ocean. There are two distinct, non-mixing stocks of albacore in the Pacific Ocean, one in the South Pacific and one in the North Pacific. Canadians have been fishing the North Pacific albacore stock since the mid-1930's (Figure 1), targeting them with troll fisheries using jigs. The North Pacific fishery lasts from late June through the end of October when albacore abundance is highest in warm waters along the west coast of North America. Albacore in the jig catch range in size from 4 kg to 15 kg and are juveniles ranging from three to five years of age.

The Canadian fishery for albacore tuna was developed as an alternative to the boom and bust cycles of the pilchard (or sardine, *Sardinops sagax*) fishery and throughout the first 50 years average annual catch was less than 100 t. Increases in reported catches to values exceeding 1,000 t annually in the 1948-1950 and 1968-1974 periods are due to enhanced catch reporting through logbook programs rather than a fishing effect, whereas the increases since the early 1990s reflect renewed interest and the subsequent development of a directed Canadian fishery targeting albacore in the North Pacific

Figure 1. Landed catches of albacore tuna by Canadian fishers from 1939 to the present. Increased catches from 1948-1950 and 1968-1974 correspond to logbook programs at the Pacific Biological Station. Data for 1939-1944 taken from Canada (1940-1945), 1945-1990 from Ware and Yamanaka (1991), and 1991 to the present from the Canadian albacore tuna catch and effort database (Stocker et al. 2007).

Historically, the majority of catch by the Canadian fleet has occurred in the EEZ of the United States, primarily off Oregon and Washington. Canadian access to these waters is governed by the Canada-U.S. Pacific Albacore Tuna Treaty, which specifies the maximum number of Canadian vessels that can enter and fish in U.S. EEZ. The annual catch has averaged

approximately 5,800 tonnes since 2000, but has declined from the record catch of 7,856 t in 2004. This recent decline reflects provisions in the Tuna Treaty, which limited Canadian access to U.S. territorial waters during the 2005 to 2008 fishing seasons and reduced availability of albacore in coastal waters. The Tuna Treaty was recently renegotiated and an increase in Canadian access was achieved for a three-year period beginning with the 2009 fishing season.

The availability of albacore in Canadian waters is strongly related to sea surface temperatures (SST) greater than 14°C (Alverson 1961; Clemens 1961; Hart 1973). Albacore catches by the Canadian fleet were concentrated in areas with SSTs between 14 and 19°C in 2008 and the distribution of catch in all months of the fishery was related to the location of these SSTs (e.g. Figure 2). Sea surface temperatures in Canadian waters were cool in 2008, and as a result the availability of albacore within Canadian waters was lower than in previous years (Figure 3). Only 4% of the total catch occurred in Canadian waters in 2008, which is lower than the 16% average for 2000-2007, and especially lower than in 2001. (Cool oceans in both years coincided with La Niña.) This low catch reflects the limited spatial and temporal availability of "tuna waters" (SST > 14 °C) within the Canadian EEZ during the 2008 fishing season.

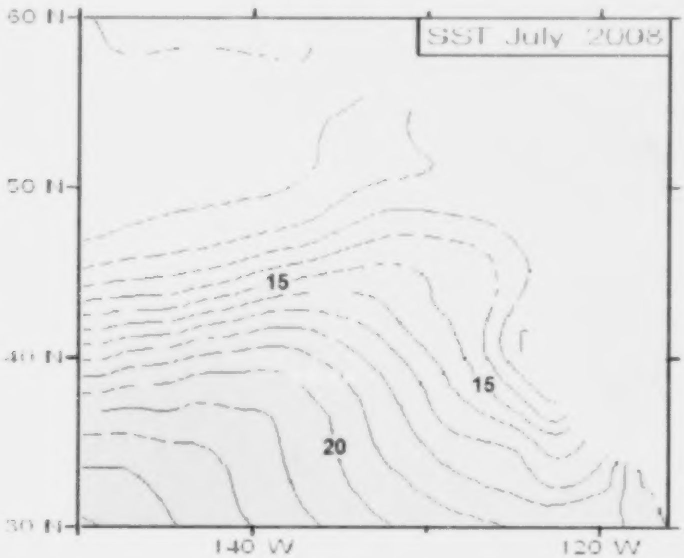


Figure 2. July 2008 albacore catch (in number of fish) reported by the Canadian fleet in relation to SST for this month. Catch data are reported on a 1° x 1° grid and each dot is located on the lower right corner of each grid cell. The size of the dots is proportional to the number of fish. Temperature isotherm interval is 1 C°. SST graphic obtained from: [illegible]

approximately 5,800 tonnes since 2000, but has declined from the record catch of 7,856 t in 2004. This recent decline reflects provisions in the Tuna Treaty, which limited Canadian access to U.S. territorial waters during the 2005 to 2008 fishing seasons and reduced availability of albacore in coastal waters. The Tuna Treaty was recently renegotiated and an increase in Canadian access was achieved for a three-year period beginning with the 2009 fishing season.

The availability of albacore in Canadian waters is strongly related to sea surface temperatures (SST) greater than 14°C (Alverson 1961; Clemens 1961; Hart 1973). Albacore catches by the Canadian fleet were concentrated in areas with SSTs between 14 and 19°C in 2008 and the distribution of catch in all months of the fishery was related to the location of these SSTs (e.g. Figure 2). Sea surface temperatures in Canadian waters were cool in 2008, and as a result the availability of albacore within Canadian waters was lower than in previous years (Figure 3). Only 4% of the total catch occurred in Canadian waters in 2008, which is lower than the 16% average for 2000-2007, and especially lower than in 2001. (Cool oceans in both years coincided with La Niña.) This low catch reflects the limited spatial and temporal availability of "tuna waters" (SST > 14 °C) within the Canadian EEZ during the 2008 fishing season.

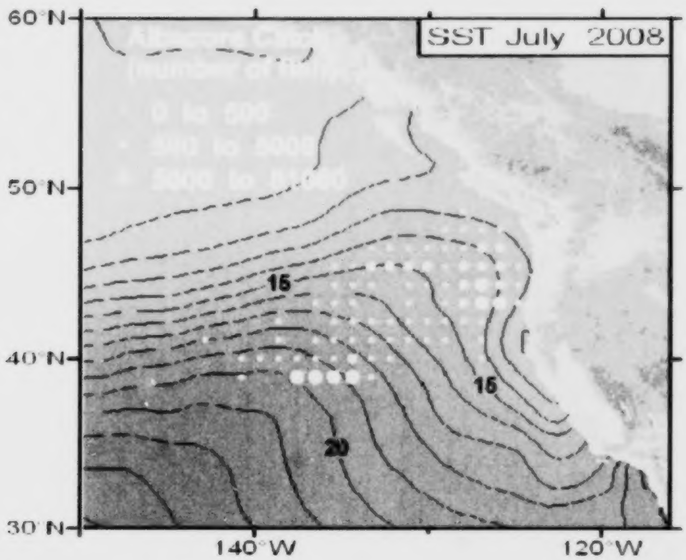


Figure 2. July 2008 albacore catch (in number of fish) reported by the Canadian fleet in relation to SST for this month. Catch data are reported on a 1° x 1° grid and each dot is located on the lower right corner of each grid cell. The size of the dots is proportional to the number of fish. Temperature isotherm interval is 1 C°. SST graphic obtained from: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/sstarchive_e.htm

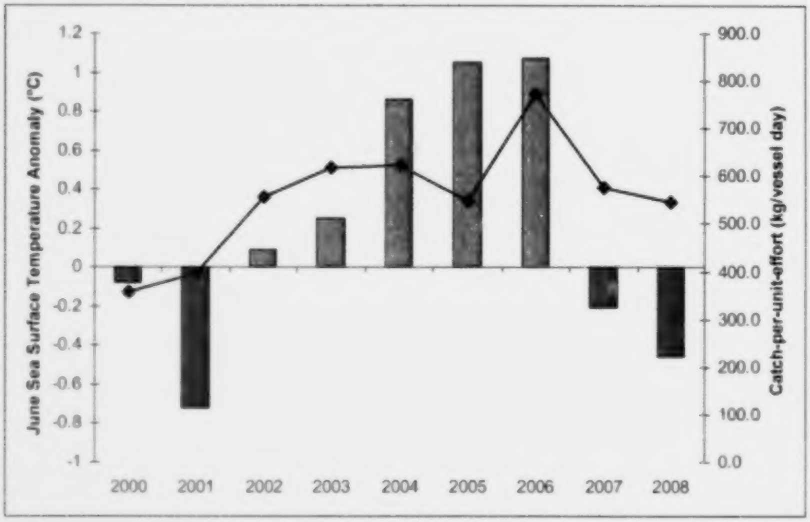


Figure 3. Availability of albacore tuna in the coastal waters of British Columbia as measured by catch-per-unit-effort (blue line) in relation to June sea surface temperature anomalies at Amphitrite Point lighthouse. Red bars indicate warmer than average June temperature and blue bars indicate cooler than average June temperature where the average is calculated for the 1956-1991 period. Temperature data were obtained from: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm

References

Alverson, D.L. 1961. Ocean temperatures and their relation to albacore tuna (Thunnus germo) distribution in waters off the coast of Oregon, Washington, and British Columbia. J. Fish. Res. Board Can. 18: 1145-1152.

Canada. 1940-1945. Tenth (to Fourteenth) Annual Report of the Department of Fisheries for the year 1939-40 (1943-44).

Clemens, H.B. 1961. The migration, age, and growth of Pacific albacore (Thunnus germo), 1951-1958. Calif. Dept. Fish Game Fish. Bull. 115: 128 p.

Hart, J.L. 1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180.

Ware, D.M., and Yamanaka, K.L. 1991. Catch statistics for the Canadian albacore tuna fishery: 1945-1990. 4 p. Department of Fisheries and Oceans, Science Branch, Pacific Biological Station, Nanaimo, BC. Document submitted to the Annual meeting of the North Pacific Fisheries Commission, Tokyo, Japan, November 1991.

Stocker, M., Stiff, H., Shaw, W., and Argue, A.W. 2007. The Canadian Albacore Tuna Catch and Effort Relational Database. Can. Tech. Rep. Fish. Aquat. Sci. 2701: vi + 76 p.

GEORGIA BASIN

Fraser River conditions in 2008

John Morrison, Vynx Design Inc.

Major rivers on both the northern and southern parts of the west coast showed similar flow patterns in 2008. Winter flows were near normal, but the onset of the spring freshet was late. On April 30 the discharges (red lines in Fig. 1.) were well blow the long term averages (black lines).

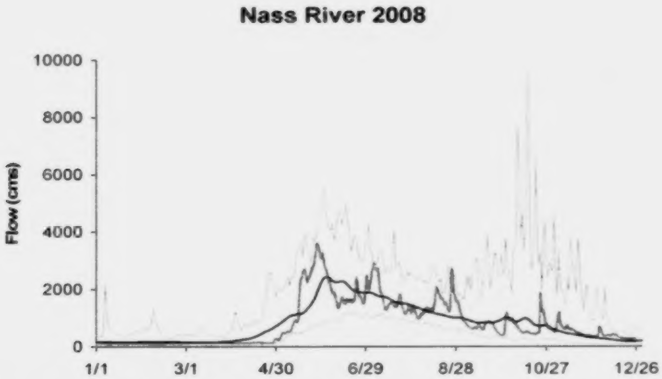


Figure 1. Nass River daily average flow in cubic meters per second (Red) with long term (1929-2005) Phase Matched Hydrograph (Black), Maximum and Minimum flows (Grey).

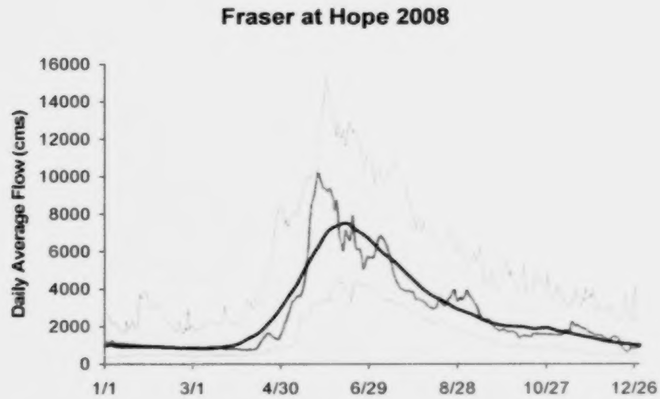


Figure 2 Fraser River daily average flow in cubic meters per second (Red) with long term (1913-2005) Phase Matched Hydrograph (Black), Maximum and Minimum flows (Grey).

When the spring melt did begin it progressed rapidly so the peak flows occurred earlier than the date when the peak flow normally occurs. Two large-scale rainfall events can be seen in the records of the rivers along the coast. The first occurred in early July and the second occurred in late August. In the autumn flows remained at near normal levels. Throughout the summer Fraser River temperatures were at, or slightly above, long term normal temperatures.

Cooling in sub-surface Strait of Georgia waters

Diane Masson, Institute of Ocean Sciences

The relatively cold conditions prevailing in sub-surface waters of the Strait of Georgia since mid 2007 have persisted and intensified through 2008. Figure 1 shows contours of temperature measured at the Nanoose station, which is located in the central deep basin of the strait (49° 18.7' N, 124° 2.7' W), since 2000. In the spring and early summer of 2008, sub-surface intrusions of colder water lowered the temperature throughout the water column. The sub-surface temperature remained relatively cold for the rest of the year. However, surface temperatures measured at Lighthouses remained above a long-term average.

Figure 2 gives the temperature anomalies at the Nanoose station relative to the average computed over the period 1970-2008. Near normal temperatures, prevalent up to mid 2003, were followed by a period of anomalously warm temperatures. This relatively warm episode ended in mid 2007 as the water column returned first to near-normal temperatures. Subsequently, cooler sub-surface conditions have become established with negative temperature anomalies prevailing during 2008, particularly in the deep strait.

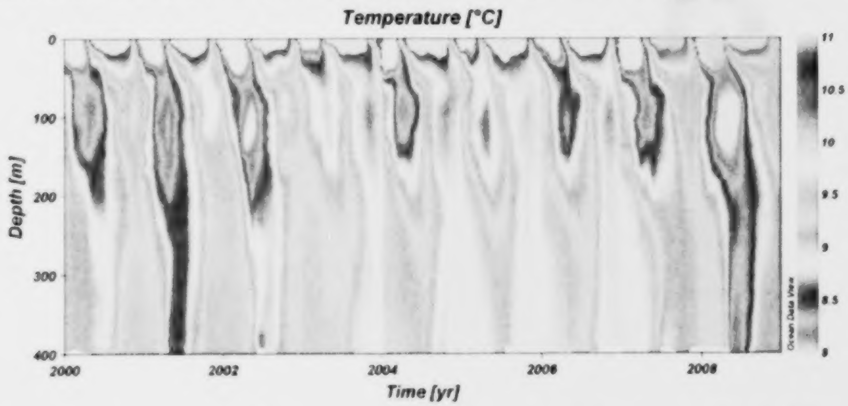


Figure 1: Contours of temperature (°C) measured at the Nanoose station (central Strait of Georgia) since 2000.

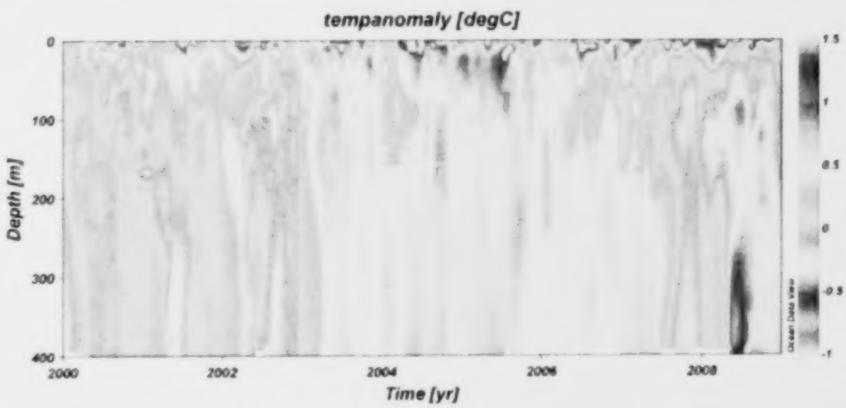


Figure 2: Temperature anomalies (°C) measured at the Nanoose station, for the period 2000-2008.

VENUS observations in the Georgia Basin

Richard Dewey, Victoria Experimental Network Under the Sea (VENUS),
University of Victoria

The Victoria Experimental Network Under the Sea is a coastal cabled observatory with arrays in both Saanich Inlet and the southern Strait of Georgia. The Saanich Inlet (SI) array includes a shore station at the Institute of Ocean Sciences (IOS) and a 3 km cable to a Node at 100m depth at the entrance to Patricia Bay. The Strait of Georgia (SoG) array consists of a shore station at the Iona waste Water Treatment Plant and a 40 km cable to two Nodes, one in the central strait at 300m depth, and a second on the eastern flank at 170m depth. At each VENUS Node there is a standard VENUS instrument platform (VIP) hosting a variety of oceanographic instruments including a CTD, an ADCP, and an inverted 200 kHz echo-sounder.

In 2008 and early 2009, VENUS completed several milestones:

- Both the 170m Eastern (Feb. 2008) and 300m Central Nodes (Sept. 2008) in the Strait of Georgia were installed
- An extension cable from the Eastern Node and a instrument platform were deployed (Feb. 2008) to 40m depth on the Fraser River delta slope (Delta Dynamics Laboratory)
- The 100m deep Saanich Inlet array completed three years of data collection in Feb. 2009
- Data available from the various sites include:
- Saanich Inlet: CTD with Oxygen/dissolved gases, inverted echo-sounder, and a digital stills camera
- Strait of Georgia Central: CTD with Oxygen and Turbidity, inverted echo-sounder, and a 150 kHz ADCP
- Strait of Georgia East: CTD with Oxygen and Transmissivity, inverted echo-sounder, and 150 kHz ADCP
- Delta Dynamics Laboratory: CTD with Oxygen and Turbidity, 600 kHz ADCP, and Imagenex scanning sonar

The data records from Saanich Inlet reveal a decrease in temperature from 2006 to 2008 at 100 metres depth (Figure 1). Time series at 100 m depth indicate that tidally modulated deep water renewal and entrainment events are associated with a seasonal warming and salinity increase over the spring and summer months (April-Oct.), followed by slightly more dramatic and highly variable cooling and freshening during the winter and early spring (Dec. – March). Seawater density (Sigma-t) is dominated by variations in salinity, with temperature providing only a weak passive tracer of warming and cooling. Deep water renewal displaces deep, low oxygen hypoxic water upward passed the VENUS site at 100m depth in the summer to fall period.

Variations in the Strait of Georgia reveal many of the same seasonal and episodic characteristics (Figure 2) evident in the Saanich Inlet data. A steady warming trend from March through October is punctuated by a few fortnightly bursts associated with tidal excursions of different water masses. Over the same period, the salinity steadily climbs, but is also modulated by fortnightly oscillations.

Seawater density continues to be dominated by salinity structure, with temperature playing only a minor and opposing role. During the summer months, large systematic variations in both temperature and salinity combine to cause significant fortnightly density fluctuations. During the cooling/freshening months of October through March, there remains a distinct fortnightly modulation of the salinity, while temperature variations are more sporadic. Much of the tidal variability is likely due to varied water masses circulating around the basin. Similar to Saanich

Inlet, dissolved Oxygen declines at this intermediate depth (170m) during the spring and summer months, and rebounds over the winter period (November – March).

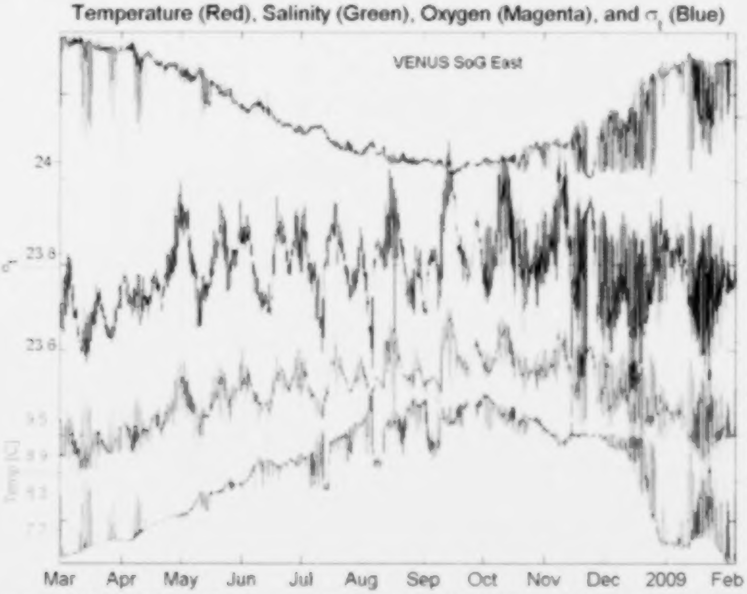


Figure 1. One year (2008) CTD & O_2 time series from VENUS Strait of Georgia East at 170m depth.

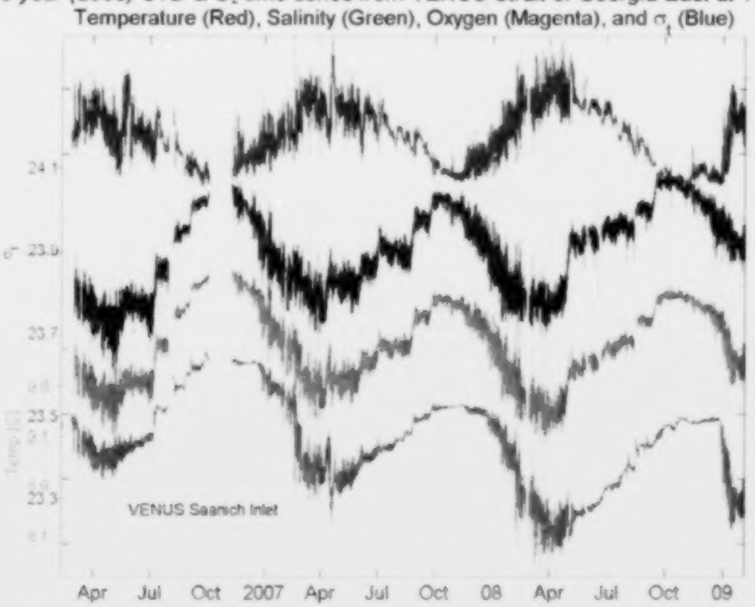


Figure 2. Three year (2006-2009) CTD & O_2 time series from VENUS in Saanich Inlet at 100m depth.

Phytoplankton in the Georgia Basin

Angelica Peña, Fisheries and Oceans Canada

Phytoplankton and nitrate concentration are measured seasonally along a 20-station transect in the Juan de Fuca / Strait of Georgia Basin (Fig. 1). The distribution of phytoplankton and nitrate concentration in the upper 15 metres during winter and summer of 2008 were similar to those observed in previous years (2002-2007). However, in spring 2008, phytoplankton and nitrate concentrations were lower in the southern Strait of Georgia, whereas in fall 2008 phytoplankton concentrations were significantly higher, and nitrate concentrations lower in Juan de Fuca Strait than in previous years.

Figure 1: Location of sampling stations in Juan de Fuca Strait and Strait of Georgia. The thick, shaded line shows the transect of stations used in Figures 2 and 3, with the numbers giving the distance in km from the mouth of Juan de Fuca Strait.

In general, nitrate concentrations are lower and chlorophyll fluorescence values (an indicator of phytoplankton biomass) are higher and more variable in the Strait of Georgia sector than elsewhere in this region (Fig. 2). Seasonally, chlorophyll concentrations in the Strait of Georgia are highest during the spring bloom (March-April), low during the summer, increasing again at the end of the summer/early fall, and lowest during winter. In contrast, in Juan de Fuca Strait, chlorophyll concentrations are usually lower than in the Strait of Georgia and remain generally low all year (<3 mg m^{-3}).

In September 2008, upper layer (0-15 m) chlorophyll concentrations in Juan de Fuca Strait were unusually high compared to the previous six years, and higher than those measured in the Strait of Georgia (Figure 2). At the same time, upper layer (0-15 m) nitrate concentrations were lower in Juan de Fuca Strait than those measured in September of the six previous years. At other locations, nitrate concentrations were similar to those observed in previous years.

The higher chlorophyll concentrations in Juan de Fuca Strait, measured as chlorophyll fluorescence during the September 2008 survey, were confirmed by independent samples of extracted chlorophyll measurements and by MODIS satellite chlorophyll during this period.

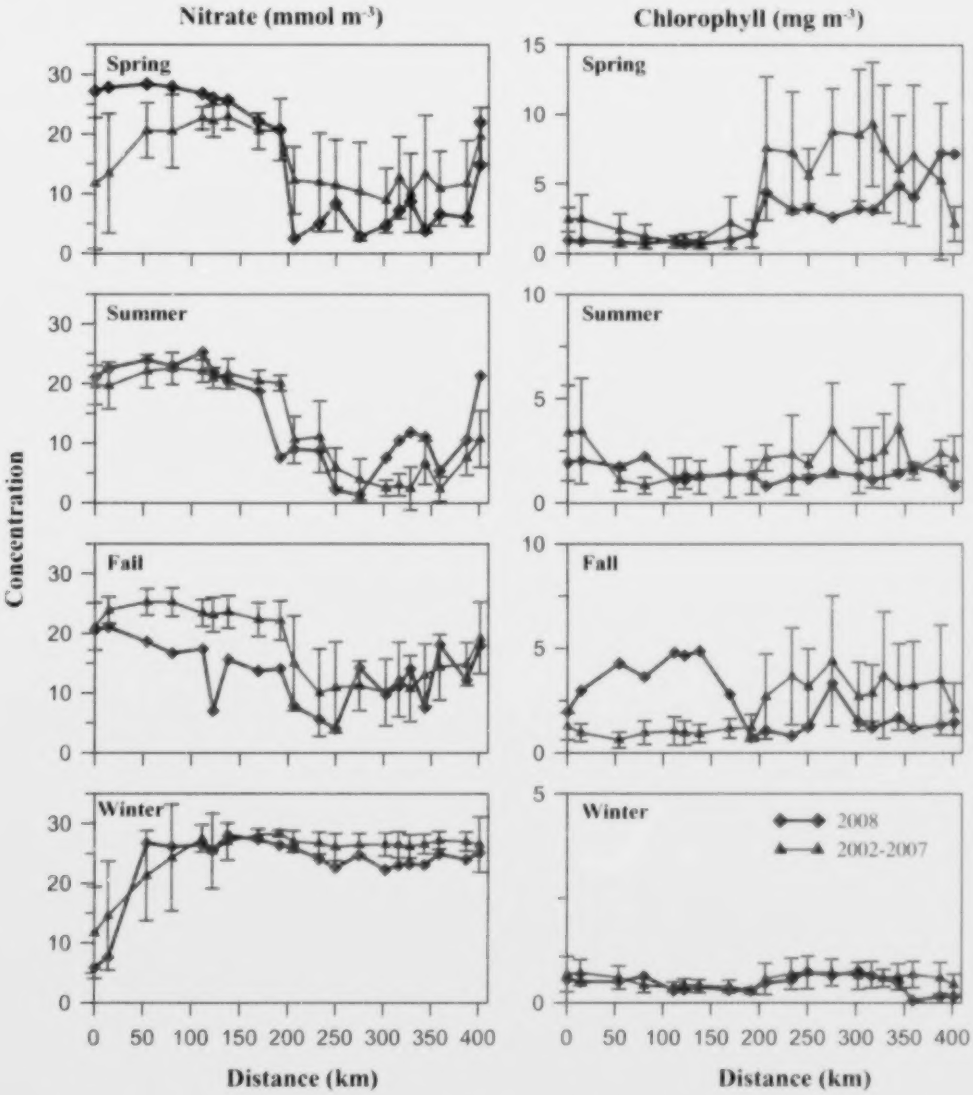


Figure 2. Upper layer (0-15 m) concentration of nitrate (left panel) and chlorophyll fluorescence (right panel) along a transect from the mouth of the Juan de Fuca Strait to the north end of the Strait of Georgia during spring, summer, fall, and winter. Blue diamonds are observations in 2008. Grey triangles and bars denote averages and standard deviations of 2002 to 2007. Numbers along lower axes are cumulative distance from the mouth of the Juan de Fuca Strait (see Figure 1).

In the spring of 2008, chlorophyll concentrations in the southern Strait of Georgia were relatively low compared to those of previous years (Figure 2). Otherwise, the distribution and concentration of chlorophyll was within the range of values observed in previous years.

In spring of 2008, the composition of phytoplankton assemblages, as determined by HPLC-derived phytoplankton pigments, was similar to those in previous years (Figure 3). Fucoxanthin was the most abundant accessory pigment at this time of the year indicating that diatoms dominated the phytoplankton community in both the Strait of Georgia and in Juan de Fuca Strait. Monitoring changes in phytoplankton composition is at least as important as monitoring changes in biomass since the transfers of phytoplankton production to higher trophic levels are mediated by the assemblage composition of the phytoplankton – diatoms, flagellates, harmful algal blooms.

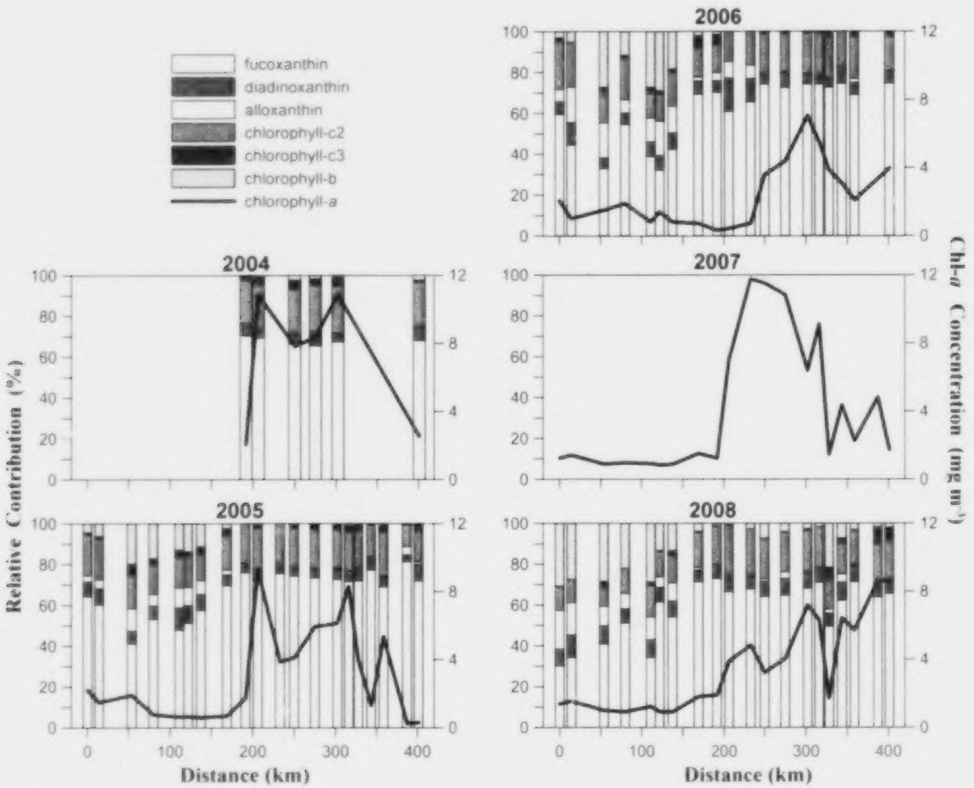


Figure 3. Relative contribution of main accessory pigments (left axis) and chlorophyll concentration (right axis) in the upper layer along a transect from the mouth of the Juan de Fuca Strait to the north end of the Strait of Georgia during spring of 2004, 2005, 2006 and 2008. Numbers along lower axes are cumulative distance from the mouth of the Juan de Fuca Strait (see Figure 1).

Prediction of the spring bloom in the Strait of Georgia

Susan Allen[1], Megan Wolfe[1], Doug Latornell[1], Jim Gower[2]
[1]University of British Columbia, and [2]Fisheries & Oceans Canada

The timing of spring blooms in the Strait of Georgia is observed to vary interannually from the beginning of March until mid-April. We have developed a one-dimensional, coupled, biophysical model of the Strait of Georgia and used it to hind-cast spring blooms. It is based on the KPP mixing-layer model (Large et al., 1994) with baroclinic pressure gradients and estuarine circulation added (Collins et al., 2009). The physical model is coupled to a simple, standard, nitrogen-phytoplankton model. The phytoplankton modelled is Thalassiosira spp. which is observed to bloom first in the Strait. Physiological parameters are taken from the literature and the model is tuned using the zooplankton biomass. The model accurately hind-casts the spring blooms of 2002-2005 for which detailed observations were made as part of the STRATOGEM project (Collins et al., 2009).

Using this model we have investigated the sensitivity of the spring bloom to physical forcings including wind, cloud fraction, temperature and river run-off. We determined a fit, based on December to February averaged wind speed cubed, cloud fraction and river outflow, to predict the spring-bloom by the end of February. Predictions, based only on the wind, made in 2006, 2007 and 2008 were accurate. In Dec 2008- Feb 2009 our weather has been unusually calm with very low river flow. It has also been cloudy (or foggy). This is an unusual year as in most years low winds imply high cloud fraction. Our prediction for the spring bloom in 2009 is March 10 to March 24. Thus we are predicting a 2009 spring bloom earlier than the previous years which was itself earlier than the previous two years. The enclosed figure shows the spring blooms for 2002-2008 with the predicted bloom for 2009. (Update: satellite observations suggest the peak bloom occurred on March 6, 2009)

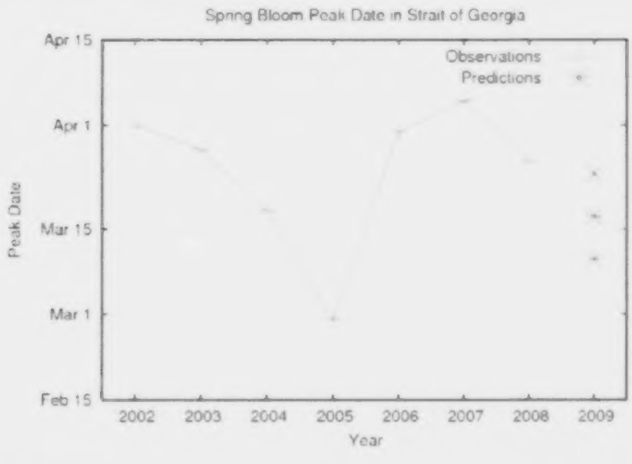


Figure 1. Observed and predicted dates of spring phytoplankton bloom in the Strait of Georgia.

References

Collins, A. K., S. E. Allen, and R. Pawlowicz, The role of wind in determining the timing of the spring bloom in the Strait of Georgia. In review by Can. J. Fish. Aquat. Sci, 2009.

Large, W. G., J. C. McWilliams, and S. C. Doney, Oceanic vertical mixing: A review and a model with a nonlocal boundary layer parameterization, Rev. Geophys., 32(4), 363–403, 1994.

Fraser River sockeye and indicators of marine survival

Sue Grant, Fisheries & Oceans Canada

Most marine mortality for salmon occurs during their early ocean residence, since this is when they are smallest and, therefore, most vulnerable to size-dependent causes of mortality (e.g. predation and starvation). Ocean conditions prior to or immediately following salmon ocean entry should determine their early marine growth rates and, consequently, their vulnerability to mortality. Improved ocean conditions that affect prey composition, quality, and abundance should increase salmon marine survival.

Ocean entry years for returning Fraser sockeye depend on the age structure of the stock (Table 1). Most Fraser sockeye are comprised of, on average, ~80% age-4 (Gilbert-Rich ageing designation 4_2) and ~20% age-5 (5_2) fish; these fish have spent their first two years in freshwater followed by their final two (4_2) or three (5_2) years in the ocean. Exceptions include Pitt River sockeye that are comprised of ~40% age-4 relative to age-5 fish and Harrison sockeye that are immediate migrants comprised of varying percentages of age-3 (3_1) and age-4 (4_1) fish.

Ocean conditions in the spring of 2008 reported in this current State of the Ocean 2008 publication will be important to the marine survival of most Fraser sockeye returning in 2010 (Table 1).

Return Year:	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
(Age Composition)			(Ocean Entry Year)				
Age-4 (4_2) *~80% of stock*	2002	2003	2004	2005	2006	2007	2008
Age-5 (5_2) *~20% of stock*	2001	2002	2003	2004	2005	2006	2007
Age-3 (3_1) *Harrison*	2002	2003	2004	2005	2006	2007	2008
Age-4 (4_1) *Harrison*	2001	2002	2003	2004	2005	2006	2007

Table 1. Ocean entry years for predominant age classes of Fraser sockeye salmon stocks associated with 2004-2010 return years. Ocean conditions during early ocean residence of salmon should determine the magnitude of total marine mortality for stocks.

Predictions for numbers of each Fraser sockeye stock returning to the river are typically based on the empirical relationship between stock size (adult spawners or juveniles) and consequent recruitment. In most cases, including ocean environmental variables as covariates in stock-recruit models has not improved forecast performance (Grant and Cass 2008, 2009). Therefore, forecasts of return abundances generally assume average marine survival conditions. If ocean conditions are below or above average or other factors such as juvenile size at ocean entry deviate from average, then this will result in the over- or under-estimation of actual returns (Fig. 1). In the 2007 return year (2005 ocean entry), for most sockeye stocks (except Harrison and Pitt), forecasts were greater than actual returns (Fig. 1). This was likely linked to the extremely poor ocean conditions for early marine salmon survival that occurred in 2005 (DFO 2006). Similarly, forecasts for Quesnel were greater than actual returns in 2005 & 2006 when Quesnel fry body sizes were below average (not accounted for in the forecasts) likely resulting in below average survival.

Marine survival for sockeye, based on the one major population where we are able to partition marine and freshwater mortality (Chilko River), has been particularly low in recent years (Fig. 2). The second lowest marine survival in the time series occurred for the 2007 return year (2005

ocean entry) at 1.4% (1961 was the lowest at 1.3%). Both Harrison and Pitt sockeye are two exceptions since these stocks have had relatively high survival and total returns in recent years compared to most other stocks. Marine survival has subsequently improved for Chilko in the 2008 return year (2007 ocean entry) to 3.4% (Fig. 2).

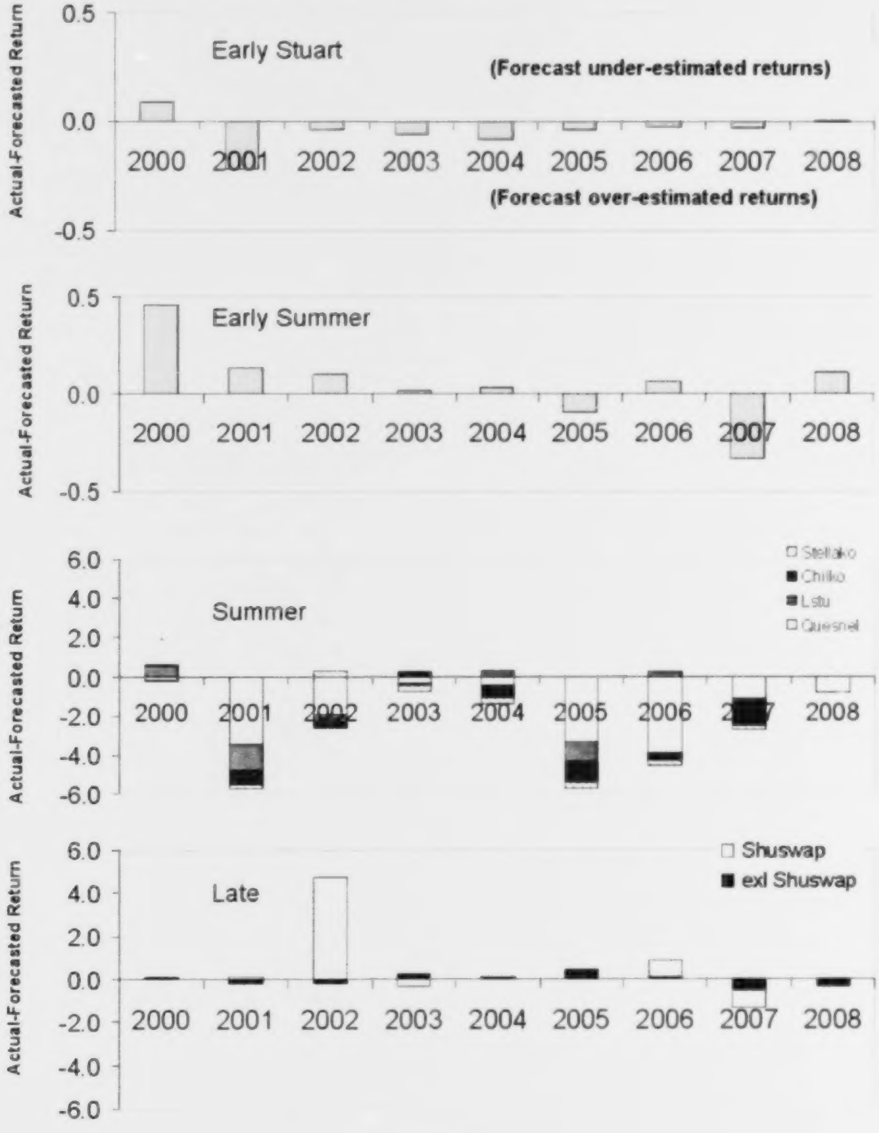


Figure 1. Forecast performance (actual minus forecasted return) for the four sockeye run timing groups. In 2007, forecasts overestimated true returns for all groups (note: Harrison is not included in the Late Run timing group plot; this stock has increased dramatically in abundance in recent years relative to all other stocks). Quesnel fry sizes in 2006 were the smallest observed on record.

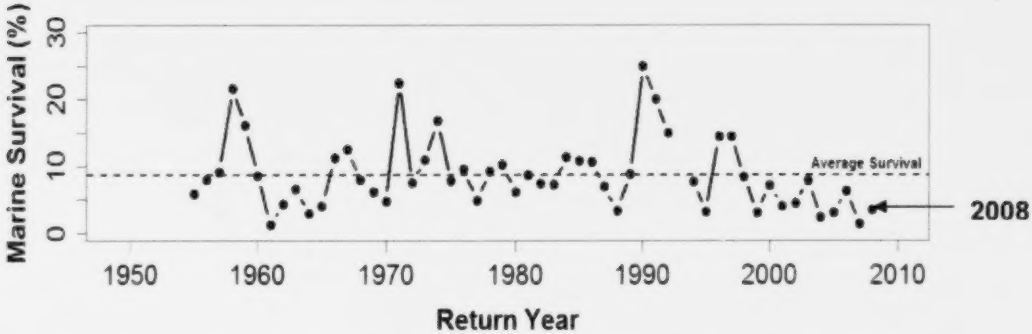


Figure 2. Chilko marine survival versus return year. The second lowest marine survival in the time series occurred in 2007 at 1.4% (1961 was the lowest at 1.3%); in 2007 the forecasts for all sockeye stocks overestimated true returns. Marine survival increased in 2008 (last data point on graph) to 3.4%. Average marine survival is 8.7%. Marine survival in the past eleven years has not exceeded the long-term average.

Sockeye return forecasts for 2009 are presented in tables as slices through a cumulative probability distribution at five probability levels: 10%, 25%, 50%, 75%, and 90% (Table 2). Probability distributions are used to capture uncertainty in forecasts using Bayesian statistics. They are presented as the probability of exceeding the specific return forecast; therefore, the smallest percentage presented (10%) has the largest associated return forecast and as the probability percentage increases, the return forecast decreases (Table 2).

In recent years, the forecast process has included recommendations to use more (>50%) or less conservative (<50%) probability levels depending on indications of, respectively, poorer or better than average ocean conditions. To provide some indication of marine survival conditions for Fraser River sockeye salmon, a compilation of ocean survival indicators for salmon are used to qualitatively compare relative ocean survival conditions from 1998 to 2007 (Table 3).

The methodology for ranking individual indicators is based on W.T. Peterson's approach (U.S. Northwest Fisheries Sciences Centre, National Ocean and Atmospheric Agency). Currently, the suite of ocean indicators explored only partially tracks Chilko marine survival (marine survival indicator system for Fraser sockeye stocks) (Table 3). This suggests that more ocean indicators need to be explored and/or developed to improve forecasting methodology.

The suite of indicators (Table 3) provided a strong indication of the very poor ocean survival conditions experienced by Fraser sockeye in 2005 (poor returns in 2007). Therefore, it may be most useful currently in providing an indication of very low marine survival. We will continue to explore the utility of this approach.

Probability of Exceeding Specified Run Sizes

Sockeye run timing group	10%	25%	50%	75%	90%
Early Stuart	645,000	426,000	255,000	165,000	107,000
Early Summer	2,284,000	1,338,000	739,000	443,000	264,000
Summer	31,813,000	16,071,000	8,677,000	4,914,000	2,858,000
Late	2,875,000	1,616,000	907,000	517,000	327,000
Total	37,617,000	19,451,000	10,578,001	6,039,001	3,556,001

Table 2. Pre-season sockeye forecasts for 2009 by run timing group and probability (Grant and Cass 2009).

(BROOD YEAR) OCEAN ENTRY YEAR **(RETURN YEAR)**	(1996) (1998) **2000**	(1997) (1999) **2001**	(1998) (2000) **2002**	(1999) (2001) **2003**	(2000) (2002) **2004**	(2001) (2003) **2005**	(2002) (2004) **2006**	(2003) (2005) **2007**	(2004) (2006) **2008**	(2005) (2007) **2009**
Chilko Marine Survival	G	Y	[illegible]	G	R	Y	[illegible]	R	Y	NA
Ocean Indices										
1 PDO (Jan-March average)	R	G	[illegible]	[illegible]	G	R	[illegible]	R	Y	Y
2 ALPI	R	G	Y	R	R	R	R	Y	G	G
Physical Conditions										
3 SST (Entrance Island)	R	G	[illegible]	G	G	[illegible]	R	R	Y	Y
4 SST (Pine Island)	[illegible]	[illegible]	[illegible]	G	Y	[illegible]	[illegible]	[illegible]	Y	G
5 Upwelling index (48°N)	G	[illegible]	[illegible]	Y	G	[illegible]	Y	[illegible]	Y	G
6 Spring transition timing (48°N)	G	[illegible]	Y	Y	[illegible]	Y	Y	[illegible]	Y	Y
Biological Conditions										
7 Southern Copepods (SVI)	R	G	Y	G	G	[illegible]	Y	[illegible]	[illegible]	G
8 Boreal Shelf Copepods (SVI)	[illegible]	[illegible]	[illegible]	Y	[illegible]	Y	[illegible]	[illegible]	[illegible]	[illegible]
9 Southern Copepods (NVI)	R	[illegible]	[illegible]	[illegible]	Y	[illegible]	Y	[illegible]	[illegible]	[illegible]
10 Boreal Shelf Copepods (NVI)	Y	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y	G

Table 3. Indicators of ocean conditions from 1998 to 2007. For each indicator, annual estimates were ranked across all years from 1 to 10 from best to worst salmon ocean survival conditions. Green (G): ranks 1 to 4; yellow (Y): ranks 5 to 7; red (R): ranks 7 to 10.

References

DFO. 2006. State of the Pacific Ocean 2005. DFO Sci. Ocean Status Report: 2006/001.

Grant, S.C.H. & Cass, A. 2008. Fraser River sockeye pre-season forecasts for 2008. pp. 106-109 In Irvine, J. and B. Crawford (Eds). 2008. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. Canadian Science Advisory Research Document 2008/013 (http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm).

Grant, S.C.H. & Cass, A. 2009. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2009. Canadian Science Advisory Secretariat (in press).

	Probability of Exceeding Specified Run Sizes				
Sockeye run timing group	10%	25%	50%	75%	90%
Early Stuart	645,000	426,000	255,000	165,000	107,000
Early Summer	2,284,000	1,338,000	739,000	443,000	264,000
Summer	31,813,000	16,071,000	8,677,000	4,914,000	2,858,000
Late	2,875,000	1,616,000	907,000	517,000	327,000
Total	37,617,000	19,451,000	10,578,001	6,039,001	3,556,001

Table 2. Pre-season sockeye forecasts for 2009 by run timing group and probability (Grant and Cass 2009).

(BROOD YEAR)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(OCEAN ENTRY YEAR)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(RETURN YEAR)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Chilko Marine Survival	G	Y	G	G	R	Y	G	R	Y	NA
Ocean Indices										
1 PDO (Jan-March average)	R	G	G	R	G	R	R	R	Y	Y
2 ALPI	R	G	Y	R	R	R	R	Y	G	G
Physical Conditions										
3 SST (Entrance Island)	R	G	G	G	G	R	R	R	Y	Y
4 SST (Pine Island)	R	G	G	G	Y	R	R	R	Y	G
5 Upwelling index (48°N)	G	G	R	Y	G	R	Y	R	Y	G
6 Spring transition timing (48°N)	G	G	Y	Y	G	Y	Y	R	Y	Y
Biological Conditions										
7 Southern Copepods (SVI)	R	G	Y	G	G	R	Y	R	R	G
8 Boreal Shelf Copepods (SVI)	R	G	G	Y	G	Y	R	R	R	G
9 Southern Copepods (NVI)	R	G	G	G	Y	R	Y	R	R	G
10 Boreal Shelf Copepods (NVI)	Y	G	G	R	G	R	R	R	Y	G

Table 3. Indicators of ocean conditions from 1998 to 2007. For each indicator, annual estimates were ranked across all years from 1 to 10 from best to worst salmon ocean survival conditions. Green (G): ranks 1 to 4; yellow (Y): ranks 5 to 7; red (R): ranks 7 to 10.

References

DFO. 2006. State of the Pacific Ocean 2005. DFO Sci. Ocean Status Report: 2006/001.

Grant, S.C.H. & Cass, A. 2008. Fraser River sockeye pre-season forecasts for 2008. pp. 106-109 In Irvine, J. and B. Crawford (Eds). 2008. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. Canadian Science Advisory Research Document 2008/013 ([illegible]).

Grant, S.C.H. & Cass, A. 2009. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2009. Canadian Science Advisory Secretariat (in press).

Juvenile salmon in the Strait of Georgia

Dick Beamish, Rusty Sweeting, Chrys Neville, Krista Lange and Dave Preikshot,
Fisheries & Oceans Canada

Marine survival of Puget Sound coho salmon continues to be superior to that of Strait of Georgia stocks, having recovered to a greater degree from the extremely low levels of both regions in the late 1990s. An examination of our midwater trawl data shows a continuous decline in the summer (May-September) survival rate of juvenile coho in the Strait of Georgia. This, in turn, is highly correlated to the total marine survival of coho from 1997-2006 (R^2=0.68; Fig. 1). One possible explanation for the lower early marine survival of Strait of Georgia coho is the higher surface water temperatures, some 1-2°C greater than observed in Puget Sound, which we believe translates into greater thermal stress as the summer proceeds. This temperature difference may be driven the by differences in oceanographic conditions between these two regions.

Chinook salmon marine survival, on the other hand, does not show the same degree of disparity between Puget Sound and Strait of Georgia stocks. Although the Puget Sound marine survival rates are generally higher, both long-term and short-term trends are the same. In 2008, we undertook a large program investigating the survival of Cowichan River chinook. As part of this program, we have analyzed a large number of DNA samples taken from midwater trawls in both the Gulf Islands and in the Strait of Georgia. Interestingly, juvenile chinook salmon captured in the Gulf Islands in July, September and November show an increasing percentage of Puget Sound chinook (2%, 6%, and 15%, respectively), demonstrating that this region may be utilized as over-winter rearing grounds by some stocks. A large number of Fraser River stocks of chinook were also observed, but declining over the summer/fall (62% in June, 43% in September, and 19% in November). We interpret this as a general movement out to the WCVI feeding grounds. Cowichan River chinook and east Vancouver Island stocks (mainly Puntledge) made up the rest of the population structure, increasing in percentage over time and comprising nearly 70% of the juvenile chinook population by November. Our preliminary interpretation is that some key populations such as the Cowichan Chinook remain in local habitats for the early marine period that determines brood year strength. Thus it is the productivity of these local areas such as the Gulf Islands that are critical to the success of these populations.

Analysis of chinook captured on the same surveys in the Strait of Georgia presented a much different picture. Puget Sound stocks were generally not found in any great percentage until November, a survey which focussed on the southern portion of the Strait of Georgia. Cowichan River chinook were also not observed in any great numbers in the Strait of Georgia, confirming our CWT data that these fish do not generally utilize these waters. While the July survey showed a wide variety of stocks in the Strait of Georgia, by September the ecosystem is dominated by South Thompson chinook (79%).

In response the recent large catches of small sockeye in our September surveys the past 3 years, we also analyzed a large number of juvenile sockeye DNA samples collected in the July, September and November trawl surveys. In July, catches of juvenile sockeye were generally confined to Howe Sound, with small catches in the northern Strait of Georgia and in the Gulf Islands. By September, catches were primarily along the mainland coast up to Malaspina Strait. By November, no sockeye were found in Howe Sound, but large numbers were still present in the Gulf Islands region. DNA analysis of these fish showed that an overwhelming percentage (97%) of the sockeye in both the Strait of Georgia and in the Gulf Islands were of Harrison River origin. Harrison River sockeye are unusual along the west coast in that they migrate to sea as fry rather than spending a winter in freshwater (akin to ocean-type chinook). It appears that this

stock of Fraser River sockeye may be exhibiting behavioural and migration patterns different than expected from the literature, and we propose that this may be reflected in the higher survival rate exhibited by this stock. If our interpretation is correct, then Harrison River sockeye are behaving more like pink salmon, and the mechanisms that relate to the improved survival are keys to understanding how the Strait of Georgia is changing.

In the past years we have forecasted adult returns in the upcoming year. These forecasts are derived from the CPUE of juvenile salmon in our July midwater trawl surveys and use the red/amber/green system. For coho salmon, the CPUE in 2008 was the lowest we have observed since 1997, therefore we are projected a very poor return in 2009. In general, we are observing reduced early marine survival for coho salmon. Our studies of Chinook salmon are preliminary and indicate very poor total marine survival (about 0.1%). Cowichan chinook from the hatchery may experience about 95% mortality by September of the first marine year. It is necessary to determine the reasons for the increasing trend of early marine mortality. We suspect that reduced growth results in an increased susceptibility to disease, but this remains speculative. Our catches of pink salmon are not related to returns, thus we have no forecast other than the general observation that the pink salmon appear to be doing well in the current regime. In 2009, we will attempt to develop forecasts for chum salmon that are based on our survey results.

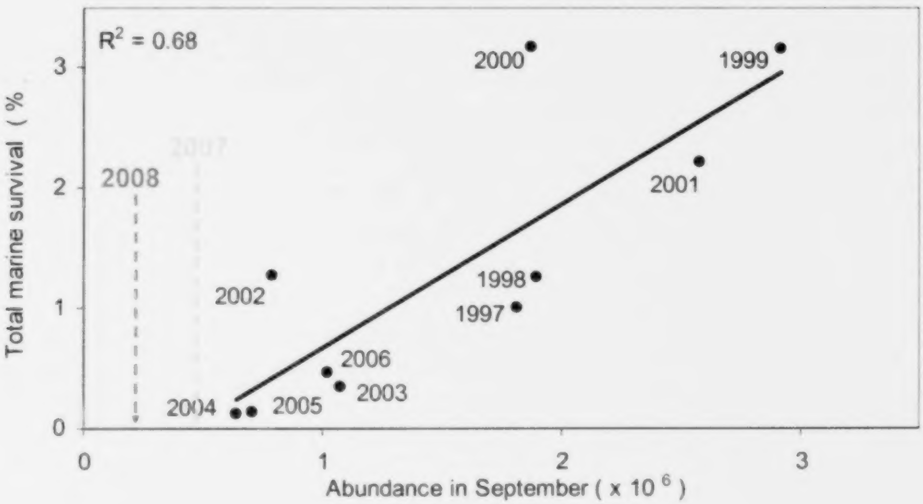


Figure 1. Relationship between September abundance of juvenile coho and marine survival in the Strait of Georgia. Final survival values for 2007 and 2008 not yet available.

Chilko Lake sockeye returns: A second look for 2009

Skip McKinnell, North Pacific Marine Sciences Organization (PICES)

Outlooks of Chilko L. sockeye returns developed by the author in 2008 and 2007 were based on relatively simple observations (Table 1). Warm SST years in southern BC have routinely led to poorer marine survival (Mueter et al. 2002) but it also appears that cold return years in the Gulf of Alaska can be detrimental, so the combination of warm out-cold home is bad. Recent work by Trudel, Mackas, Beckman, Peterson, and others (pers. comm.) has shown that a warm surface ocean is simply a surrogate indicator for a suite of ecological changes in the coastal ocean environment and food web that are generally detrimental to salmon growth and survival.

The "cold home" part of this outlook is a new hypothesis that a cold spring in the Gulf of Alaska is an indication of delayed/reduced biological productivity when maturing salmon need food the most (for growth, for maturation, for homeward migration, and for upriver migration and spawning). It entertains the idea that salmon will die at sea if they don't have access to adequate food for these energetically demanding activities. Correlations of Gulf of Alaska SST during the return year with smolt to adult survival are as strong as correlations between ocean entry year SST and smolt to adult survival over the last 50 years.

Furthermore, smolt to adult survival of Georgia St. coho is used as a leading indicator of sockeye marine survival because these coho return to spawn one year earlier but share a common ocean entry year and location with the Chilko L. sockeye.

None of these ecological relations provide strong descriptive powers (account for large percentage of variance in returns), let alone predictive power. The single most reliable indicator of Chilko L. sockeye returns is simply the number of sockeye smolts that emigrated from Chilko L. Previous outlooks in 2007 and 2008 were developed from a combination of these predictors.

The major challenge to developing an outlook for 2009 is the number that left the lake in 2007. It was twice the previous observed maximum (PICES 2008), i.e. vastly exceeding anything observed in the last 50 years.

Return Year	Observed returns (,000)	McKinnell's outlook (,000)	DFO 50% forecast (,000)
2007	322	Less than 560, maybe a lot less	1,700
2008	386	300-800	880
2009	Stay tuned	1,000-3,000	4,100

Table 1. Performance of previous outlooks and comparison with official forecasts.

About seventy-seven million smolts left Chilko L. for the sea in 2007 and no one knows what happens to them at this high abundance. Will the marine survival diminish from too few resources for them all? In that case, a model with some downward curvature at high smolt abundance would be better than a linear model (more smolts = more adults). Another troublesome feature of the Chilko L. sockeye data is the tendency over the last 50 years for the least reliable outlooks to occur at high smolt abundance. Years with the three largest numbers of smolts have all fallen significantly below expectations upon their return.

Applying the worst marine survival observed in history of Chilko L. sockeye (1.38% from the 2005 ocean entry year) times the huge numbers of 2007 smolts produces an estimated return in 2009 of 1 million adults; let's consider this as a lower bound on expected returns. Ocean

temperatures along the BC coast during 2007 were generally cool except for a period in July and August when they were about 0.5 to 3.5 degrees Celsius higher than the long term (since 1935) average for that time of year. Spring temperatures on the west coast in 2007 were below average and that tends to be associated with better survival of Chilko L. sockeye. The effect of two months of a warmer ocean is not yet predictable but lower than average growth of juvenile salmon was observed by Marc Trudel in 2007 along the coast and lower than average marine survival was observed in many B.C. coho salmon stocks that entered the ocean in the same year.

Summary

While I don't think that survival for the 2009 return year will be as bad as 2007 return year, it should be sufficient to produce 1-3 million adult sockeye returns to Chilko Lake. The wide bounds are because it is hard to predict what will happen to 77 million smolts from one lake.

References

McKinnell, S.M. and Crawford, W.R. 2007. The 18.61 lunar nodal cycle and surface temperature variation in the northeast Pacific Ocean. Journal of Geophysical Research 112, C02002, doi:10.1029/2006JC003671.

McKinnell, S.M. and Mantua, N.J. In prep. An high resolution PDO and its low frequency variation.

Mueter, F.J., R.M. Peterman, and B.J. Pyper. 2002. Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (Oncorhynchus spp.) in northern and southern areas. Can. J. Fish. Aquat. Sci. 59: 456–463.

PICES 2008. The 2009 Vintage of Fraser River Sockeye Salmon; a complex full bodied redd with mysterious overtones. PICES Press 16(1).

Trudel, M., Baillie, S., Parken, C., and O'Brien, D. 2008. Average growth for coho salmon in southern BC. pp. 82-83 In Irvine, J. and B. Crawford (Eds). 2008. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. Canadian Science Advisory Research Document 2008/013 http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm